3.0 AFFECTED ENVIRONMENT AND ENVIRONMENTAL CONSEQUENCES

This chapter describes the environmental baseline conditions and impact analysis of the drilling sites and access roads. This environmental analysis follows the USFS (*Environmental Policy and Procedures Handbook 1909.15-92-1*) and the BLM NEPA guidance documents (*H-1790-1*). The BLM's NEPA Handbook requires that all EAs address certain Critical Elements of the Human Environment. These critical elements are listed below along with the location in the chapter where the element is discussed. If the element does not occur within the project area or would not be affected, this is indicated below and the element is not discussed further in the EA. The elimination of nonrelevant issues follows the CEQ guidelines stated in 40 CFR 1500.4. Other non-critical element resources such as soils, geology, minerals, vegetation, grazing, wildlife, noise, recreation, visual resources, transportation, socioeconomics, and health and safety are included in the analysis.

- Air Quality - Section 3.1.
- Areas of Critical Environmental Concern - would not be affected.
- Cultural Resources - Section 3.11.
- Drinking Water/Groundwater Quality - Section 3.4.
- Environmental Justice - non-issue but addressed in Section 3.13.
- Floodplains - Section 3.4.
- Hazardous or Solid Wastes - Section 3.14.
- Invasive Non-native and Noxious Plant Species - Section 3.5.
- Migratory Birds - Section 3.6.
- Native American Religious Concerns - Section 3.11.
- Paleontological Resources - would not be affected.
- Prime or Unique Farmland - would not be affected.
- Threatened, Endangered, Candidate, or Sensitive Species - Section 3.7.
- Wetlands and Riparian Zones - Section 3.5.
- Wild and Scenic Rivers - would not be affected.
- Wilderness - would not be affected.
- Wild Horses - would not be affected.

The analysis of impacts of the Proposed Action and No Action Alternative addresses resource issues listed in Section 2.3. The impact discussion for each resource includes information applicable to all sites followed by site-specific impacts. The site-specific impact discussion focuses on information unique to particular well sites. The impact analysis of the Proposed Action assumes the implementation of design features identified in Section 2.1.12. Potential additional mitigation was developed in response to anticipated impacts for some resources to further reduce effects of the Proposed Action. These measures are discussed at the end of each resource section. Residual adverse impacts are those impacts remaining after consideration of the design features of the Proposed Action and applying additional mitigation measures. Descriptions of short-term uses compared to long-term productivity and irreversible or irretrievable commitments of resources are provided at the end of the chapter.

As previously discussed in Chapter 2.0, the exact timing of project activities would depend on permit approval, completion of the NEPA requirements, rig availability, and other such factors. In terms of the project schedule, it is assumed that construction (2 to 7 days per well site) and drilling and completion (12 weeks for all eight well sites) could occur within year 1. By analyzing this project schedule, maximum traffic and associated human activity would be addressed in the analysis. If the wells are drilled and completed in years 1 and 2, impacts would be less than the completion of these activities in year 1.

The analysis of cumulative effects considers the effects of the Proposed Action on a given resource, in combination with residual effects of past actions, current effects of ongoing activities, and effects associated with foreseeable future actions. In some instances, the effects of past and ongoing activities may be reflected in the description of existing conditions or affected environment. The scope of actions considered for the cumulative effects analysis is not limited to federal actions, but rather includes all actions and activities that affect the resource, ecosystem, or human community, no matter what entity has taken the actions.

The cumulative effects analysis focuses on other actions that are reasonably identifiable in terms of the type and scope of the action, geographic location, timing, and likelihood. Cumulative effects analyses are not required to speculate on "what ifs" or "hypothetical" actions or scenarios, or to develop a worst-case analysis, rather it should include reasonably foreseeable actions that occur in a time and location wherein the effects of the Proposed Action and those of the other actions coincide, accumulate, or interact synergistically. Furthermore, the cumulative analysis need not speculate on potential detailed future cumulative effects in instances where the outcomes of a specific Proposed Action may result in yet other future actions, where those actions would themselves be subject to both project-specific and cumulative effects analysis. For example, in this instance, the potential project-specific and cumulative effects associated with a natural gas production program on federal leases on the GMUG need not be addressed in detail as additional permitting and NEPA analysis would be required for such a program to progress. The future NEPA analysis would have the benefit of the specific parameters regarding the natural gas production program and other on-going actions, as well as additional insights into the then reasonably foreseeable future actions. When considering the potential well production, it is assumed that pipelines would follow existing roads, which would reduce additional new surface disturbance.

Potential cumulative effects on each resource were assessed for the eight well exploration program and the past, present, and reasonably foreseeable future actions listed in **Table 2-9**. The scope of the cumulative assessment reflects the scale, intensity, and duration of the project-related effects; the wide geographic dispersion of the eight wells; the limited information regarding the timing, location, likelihood, characteristics, and features of the other actions; and the need for future project-specific NEPA analysis prior to initiation of production from any of these eight wells. The cumulative effects analysis is based on the potential direct and indirect effects of the eight well exploration program without mitigation; implementation of applicable mitigation measures would reduce potential direct, indirect, and cumulative effects. The cumulative effects analysis considers GEC's four private well sites, which would be initiated in the summer or fall of 2003 or spring of 2004. The exact schedule for these well sites in relation to the public well sites is not known. However, it is assumed that one or more of the private well sites could be sequenced in with the activities at the public well sites. This approach would address maximum potential cumulative effects for these wells.

Potential additional mitigation measures are provided at the end of each resource section, as applicable. Mitigation measures are based on standards and guidelines discussed in Appendix H of the GMUG Oil and Gas Leasing Final EIS, or other federally-based standards. The decision makers have the opportunity to choose which of these mitigation measures would be carried forward in the decisions as Conditions of Approval (see Sections 1.4 and 2.6).

3.1 Air Quality

3.1.1 Affected Environment

The study area for air resources includes the areas accessible to the public in the immediate vicinity of the well sites and along access roads. The cumulative effects area includes the region encompassing overlapping impacts from other existing major sources, which comprise any air pollution sources related to past, present, and future actions, and Class I areas within 62 miles (100 kilometers).

The surrounding terrain consists of mountain ranges and river valleys. Elevations range from approximately 5,500 feet above mean sea level (amsl) in the North Fork of the Gunnison River valley, to more than 13,000 feet amsl in the West Elk mountains. Moderately high terrain is located on Grand Mesa with elevations above 10,000 feet amsl.

Air quality in Delta and Gunnison counties is considered good in terms of meeting state and National Ambient Air Quality Standards (AAQS). Windblown dust and wood stoves are believed to be the most prevalent air pollutant emission sources in the region, which is the reason for particulate matter monitoring in these counties. Measured PM_{10} concentrations in the Paonia and Cedaredge areas are well within state or National AAQS. In 1996 and 1997 the annual average PM_{10} concentrations were 16 and 17 micrograms per cubic meter ($\mu g/m^3$), respectively. The 24-hour second highest concentrations were 24 $\mu g/m^3$ in 1996 and 35 $\mu g/m^3$ in 1997. This compares to the AAQS of 50 $\mu g/m^3$ and 150 $\mu g/m^3$ annual and 24-hour limits. Short-term excursions in particulate concentrations occasionally occur during dust storms, as indicated by a measured value of 467 $\mu g/m^3$ on March 31, 1999. Natural occurring events such as this do not affect an area's designation as in attainment of AAQS.

The cumulative effects area encompasses a wide range of terrain and elevations. At lower elevations in western Colorado, the climate is classified as semi-arid, which is characterized by low rainfall, low humidity, clear skies, and relatively large annual and diurnal temperature ranges. However, extreme variations in climate occur over short horizontal distances due to terrain and elevation differences. At higher elevations where the Proposed Action would take place, precipitation may be much more plentiful, exceeding 35 inches per year.

Because of the dry atmosphere, bright sunny days and clear nights frequently occur, which result in rapid heating of the ground surface during daylight hours and rapid cooling at night. Since heated air rises and cooled air sinks, winds tend to blow uphill during the daytime and downslope at night. This upslope and downslope cycle generally occurs in all areas of the local geographical features, including mountain range slopes and river courses. The larger the horizontal extent of the feature, the greater the volume of air that moves in the cycle. Terrain features can cause complex movements in the cyclic air patterns, with thin layers of moving air embedded within the larger scale motions. The lower level, thermally driven winds also are embedded within larger scale upper wind systems (synoptic winds). Synoptic winds in the region predominantly move in a west-to-east direction.

3.1.1.1 Climatology and Meteorology

Three important meteorological factors influence the dispersion of pollutants in the atmosphere: mixing height, wind (speed and direction), and stability. Mixing height is the thickness of the layer of air above ground within which rising warm air from the surface mixes by convection and turbulence. Local atmospheric conditions, terrain configuration, and source location determine the degree to which pollutants are diluted in this mixed layer. Mixing heights vary diurnally, with local weather systems, and with season. For the project study area, the mean annual morning mixing height is estimated to be approximately 900 feet, and the mean annual afternoon mixing height is approximately 7,900 feet (Holzworth 1972).

Long-term climate data are available at a National Oceanic and Atmospheric Association cooperative site in Paonia, Colorado, and monthly average maximum and minimum temperatures and average precipitation are shown in **Table 3.1-1**. The total annual precipitation averages about 16 inches per year. Warmest daytime temperatures typically occur in July with an average maximum of nearly 89ºF, and coldest temperatures occur in January with an average maximum of 38ºF. Average minimum temperatures range from about 13ºF in January to over 55ºF in July.

The project study area is located at a latitude that places it within the belt of prevailing westerly winds that circle the globe around the earth's northern hemisphere. However, complex terrain strongly influences the winds that are affected by local topographic features, including numerous creeks and smaller drainages as well as the larger North Fork River Valley. Winds generally blow either up or down the valley parallel to the major mountain ranges. Wind speed has an important effect on area ventilation and the dilution of potential pollutant concentrations from individual sources. Light winds, in conjunction with large source emissions, may lead to an accumulation of pollutants that can stagnate or move slowly to downwind areas. During stable (i.e., temperature increase with height above ground) conditions, downwind usually means down valley or toward lower elevations.

Morning atmospheric stability conditions tend to be stable because of the rapid cooling of the layers of air nearest the ground. Afternoon conditions, especially during the warmer months, tend to be neutral (i.e., temperature is nearly constant or decreases slowly with height above ground) to unstable (i.e., temperature decreases more rapidly with height above ground) because of the rapid heating of the surface under clear skies. During the winter, periods of stable afternoon conditions may persist for several days in the absence of synoptic scale storm systems to generate higher winds with more turbulence and mixing. A high frequency of inversions in the valleys during the winter can be attributed to nighttime cooling and sinking air flowing from higher elevations to the low-lying areas in the valleys. Although winter inversions are generally quite shallow, they tend to be more stable because of reduced surface heating.

3.1.1.2 Air Quality

Air quality is defined by the concentration of various pollutants and their interactions in the atmosphere. Measurement of pollutants in the atmosphere is expressed in units of parts per million or $\mu g/m^3$. Both long-term climatic factors and short-term weather fluctuations are considered part of the air quality resource because they control dispersion and affect pollutant concentrations. Physical effects of air quality depend on the characteristics of the receptors and the type, amount, and duration of exposure. Air quality standards specify acceptable upper limits of pollutant concentrations and duration of exposure. Air pollutant

Table 3.1-1
Monthly Climate Summary for the Paonia Area[1]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Maximum Temperature (^{0}F)	38.4	45.0	53.5	62.7	72.9	83.4	88.8	86.3	77.9	66.6	52.2	40.3	64.0
Average Minimum Temperature (^{0}F)	13.4	20.3	27.3	33.8	41.4	48.9	55.7	54.4	46.6	36.3	25.9	16.0	35.0
Average Total Precipitation (inches)	1.26	1.21	1.61	1.46	1.47	0.80	1.08	1.34	1.47	1.63	1.33	1.33	15.99
Average Total Snowfall (inches)	12.5	9.2	6.6	2.6	0.2	0.0	0.0	0.0	0.0	0.8	4.8	12.0	48.9
Average Snow Depth (inches)	4	3	0	0	0	0	0	0	0	0	0	2	1

[1]Period of Record: 2/1/1905 to 12/31/2001.

Source: National Climatic Data Center – National Weather Service Cooperative Network 2002.

concentrations within the standards are generally not considered to be detrimental to public health and welfare.

The relative importance of pollutant concentrations can be determined by comparison with an appropriate national and/or state AAQS. Colorado AAQS are presented in **Table 3.1-2**. These are the standards applicable to the project area, and are at least as stringent as the National AAQS. An area is designated as "in attainment" for a pollutant if ambient concentrations of that pollutant are below the AAQS. An area is not in attainment if violations of AAQS for that pollutant occur. Areas where insufficient data are available to make an attainment status designation are listed as unclassifiable and are treated as being in attainment for regulatory purposes.

Table 3.1-2
Ambient Air Quality Standards for the State of Colorado

Pollutant	Averaging Time	Quality Standards[1] ($\mu g/m^3$)
Ozone	1-hour	235
Ozone	8-hour	157
CO	1-hour	40,000
CO	8-hour	10,000
SO_2	3-hour	700
SO_2	24-hour	100
SO_2	Annual average	15
NO_2	Annual average	100
PM_{10}	24-hour	150
PM_{10}	Annual average	50
$PM_{2.5}$	24-hour	65
$PM_{2.5}$	Annual average	15

[1]Standards other than annual averages are not to be exceeded more than once per year.
[2]SO_2 AAQS for the State of Colorado.

Note: All air quality measurements are corrected to a reference temperature of 25º Celsius and to a reference pressure of 760 millimeters of mercury (1,013.2 Millibars).

Source: Colorado Department of Health - AQCC Regulations 2002.

The Paonia and Cedaredge areas are designated as a Prevention of Significant Deterioration (PSD) Class II area. The Class II designation allows for moderate growth or some degradation of air quality within certain limits above baseline air quality. The release of limited amounts of certain pollutants is allowed as long as AAQS are maintained, and for a major source, emissions must remain within the Class II increment. The closest PSD Class I area (minimal air quality deterioration is allowed) is the West Elk Wilderness Area, located approximately 6 to 8 miles south/southeast of Somerset. Each of the proposed well sites is less than 30 miles from the West Elk Wilderness Area.

The actual concentration of sulfur dioxide (SO_2) at any given receptor site (no greater than 5 meters above ground level) in the State of Colorado shall not exceed a 3-hour maximum of 700 $\mu g/m^3$ more than once in any 12-month period. The ambient standards for SO_2, as presented in **Table 3.1-3**, are expressed as allowable amounts of increase in ambient concentration (increments) over an established baseline. All concentrations are expressed in $\mu g/m^3$ (actual) under local conditions of temperature and pressure.

Table 3.1-3
Allowable Incremental Increase in
Ambient SO_2 Concentration by PSD Class Area

Averaging Period	Category I (Incremental)	Category II (Incremental)	Category III (Incremental)
Annual Arithmetic Mean	2	10	15
24-Hour Maximum	5	50	100
3-Hour Maximum	25	300	700

The 24-hour and 3-hour SO_2 standards are not to be exceeded at any given receptor site more than once in the 12-month period. The "baseline" for these incremental standards is defined as that concentration of SO_2 either measured or estimated by the CDPHE to exist on the effective date of Air Quality Control Commission (AQCC) Regulation No. 3.

3.1.2 Environmental Consequences

3.1.2.1 Proposed Action

Impacts Applicable to All Sites

The principal sources of fugitive dust would be related to construction activities, including road building, land clearing, and drilling operations. In addition, other fugitive emission impacts would be caused by mud/dirt carryout onto paved surfaces. Air quality effects from construction would result in minor temporary impacts due to increases in local fugitive dust levels. Dust generated from these open sources is termed "fugitive" because it is not discharged to the atmosphere in a confined flow stream (e.g., stack, chimney, or vent).

Particulate levels from construction, operation, and reclamation activities would vary, and impacts would depend on the activity location and the daily wind and weather. Some level of fugitive dust emissions would be unavoidable due to the nature of the work. Fugitive dust resulting from vehicle traffic would be reduced from the design feature of using a dust suppressant on the access roads. Although some impacts on air quality would inevitably occur during construction, they would be dispersed, transitory, and limited in duration, and would end at the completion of that particular phase of the work. Once construction was completed, fugitive dust concentrations would return to background levels. During construction, testing, and reclamation, vehicle exhaust emissions would be generated, but such emissions are generally small compared to fugitive emissions from road or well pad construction. Impacts to the environment and to human health would be very minor.

Minor air quality impacts due to emissions from well site completion and testing activities would occur in the immediate vicinity of the wells throughout the initial phase of the project. The primary pollutants would be fugitive dust and fugitive VOCs. Flare emissions would include nitrogen dioxide (NO_2), CO, SO_2, and VOCs. All criteria pollutant emission rates would be less than 250 tons per year (**Table 3.1-4**); therefore, the Proposed Action would not be a major stationary source as defined by the USEPA; air pollutant sources are deemed major for PSD purposes, if their emissions exceed 250 tons per year. The well sites potentially would be minor sources for criteria pollutants and would be required to obtain minor source air permits from CDPHE (Permit Information, Appendix A, **Table A-1**). Well site emissions may contain low levels of hazardous air pollutants in the VOCs and flare emissions. However, the quantities are expected to be below reportable levels. Small quantities of methane and CO_2 may be released by fugitive emissions and combustion sources, respectively, but these minor emissions would not measurably affect greenhouse gas levels. Impacts from well site emissions would not be expected to affect human health or the environment.

The following assumptions were made to estimate drilling emissions:

- Two each, 500 horse power diesel engines, 25 days per well at 0.47 capacity;
- Proposed Action would result in 8 wells;
- Each well would produce 200,000 ft^3/day;
- No compressor stations;
- No tanks at well sites;
- Fleet average SO_2 = 0.273 gallon per mile;
- Fleet average CO = 30 gallons per mile;
- Fleet average NO_x = 7 gallons per mile;
- Fleet average unburned hydrocarbons = 4 gallons per mile; and
- Heat value of gas is 1,189 Btu/ft^3.

Methane is a greenhouse gas, and any leaks of methane from the wells would constitute greenhouse gas emissions. Most of the methane produced by individual wells would be consumed in lighted flares until such time that the well is shutdown or a gathering system is put in place. No gathering system is included in the Proposed Action.

Fugitive dust and vehicle exhaust from construction activities, along with air pollutants emitted during operation (i.e., well operations, injection well and pipeline compressor engines, etc.), are potential causes of decreases in air quality.

Construction emissions would occur during potential road and well pad construction, well drilling, and well completion testing. During well completion testing, natural gas may be flared and exhausted. Since the burned natural gas is "sweet" (does not contain sulfur compounds), no objectionable odors are likely to occur during the drilling or completion of wells.

Diesel generators, if used on the proposed project, would produce emissions of NO_2, CO, SO_2, VOCs, PM_{10}, and particulate matter less than 2.5-micron aerodynamic diameter ($PM_{2.5}$). There are no plans to use diesel generators at the well sites on a permanent basis; therefore, any impacts would be limited in duration and below reportable limits for all pollutants.

Ozone is a pollutant not directly emitted by any source in the Proposed Action. However, emissions of VOCs from engines and well site facilities have the potential to be transformed in the atmosphere into ozone. Total annual emissions of VOCs from all sources in the Proposed Action would not appreciably affect ground-level ozone in the local area or in the region, since the VOC emissions levels are quite small and widely dispersed throughout the proposed project area. The following table (**Table 3.1-4**) shows the estimated annual emissions of criteria pollutants in tons per year for the various processes associated with drilling the proposed well sites.

Table 3.1-4
Estimated Annual Emissions of Criteria Pollutants

	Estimated Annual Emissions (tons/year)[1]				
	VOCs	**NO_x**	**SO_2**	**CO**	**PM_{10}**
Process					
Fugitive dust/well pads	0.0	0.0	0.0	0.0	0.5
Drilling	2.8	35.0	2.3	7.5	2.5
Flares[2]	2.6	84.0	2.6	179.2	2.6
Mobile Sources (Vehicles)					
Drill rigs	0.002	0.004	0.000	0.017	0.099
Large service trucks	0.002	0.004	0.000	0.017	0.085
Pickups, etc.	0.022	0.039	0.002	0.165	0.059
Total Project	**5.4**	**122.1**	**4.9**	**186.9**	**5.8**

[1]All Emission Factors (USEPA 1995a).

[2]AP-42 **Table 13.5-1** (English Units), Emission Factors for Flare Operations (USEPA 1995a).

During construction, particulate matter emissions from well pad and resource road construction would be minimized by application of water. The control efficiency of dust suppression by water application can range as high as 80 percent during construction, depending on the frequency and volume of water applied.

Potential direct project air quality impacts would not violate any local, state, or federal air quality standards in the nearby West Elk and Raggeds Wilderness areas. Agricultural production, including organic orchards in the North Fork Valley and near Cedaredge, would not be affected by the Proposed Action since potential direct project air quality impacts and cumulative impacts would not violate any local, state, or federal air quality standards.

The proposed exploratory wells do not represent a source of airborne silica. Silica may be present in fugitive dust from unpaved roads and due to wind erosion from disturbed acreage. Silica emissions from well pad and resource road construction would be minimized by application of water. Potential direct project air quality impacts would not violate any local, state, or federal air quality standards.

Maximum air pollutant emissions from each well would be temporary (i.e., occurring during a short construction period) and would occur in isolation, without significantly interacting with adjacent well locations.

Existing air pollutant emission sources within the region include the following:

- Exhaust emissions, primarily CO and NO_2, from stationary natural gas fired engines used in production of natural gas;
- Mobile source emissions from gasoline and diesel vehicles such as VOCs, CO, NO_2 PM_{10}, $PM_{2.5}$, and SO_2;
- Dust generated by vehicle travel on unpaved roads, and windblown dust from neighboring areas;
- Transport of air pollutants from emission sources located outside the region; and
- Dust (particulate matter) from coal mining operations.

This NEPA analysis compares potential air quality impacts from the Proposed Action and alternatives to applicable AAQS, and air quality related values (such as visibility), but it does not represent a regulatory PSD analysis. Even though the development activities would occur within areas designated PSD Class II, the potential impacts are not allowed to produce effects greater than the more stringent Class I thresholds to occur inside any distant PSD Class I area.

All sources are required to obtain a construction permit unless they are specifically exempted by the provisions of AQCC Regulation No. 3. The permitting process and requirements involve a two-phased approach, described in Appendix A, **Table A-1**.

Site-specific Impacts

No unique or specific air quality impacts were identified for individual well sites.

3.1.2.2 No Action

Under the No Action Alternative, there would be no project-related effect on air quality in the area, since the project activities would not occur.

3.1.3 Cumulative Impacts

Past, present, and future actions with the potential for cumulative air emissions include natural gas well development, continued coal mining and exploration drilling, road construction, emissions from normal traffic, and wildfires. These activities could contribute to emissions of fugitive dust from roads or other disturbed areas or criteria pollutants.

Based on the summary of potentially interrelated actions in **Table 2-9** and **Tables F-1** and **F-2** in Appendix F, there is a potential that approximately 50 percent of the exploration wells in the lease areas could be developed into production wells; it is estimated that these wells could be in place for up to

40 years. Pipelines would be constructed, likely along access roads, to tie into larger lines. Cumulative fugitive dust emissions from the Proposed Action would depend on the timing and location of the natural gas development relative to the proposed exploratory drill sites; cumulative impacts are anticipated to be minor and would be temporary (up to 3 years) in duration. Due to the very low criteria pollutant emissions associated with the Proposed Action, no cumulative impacts are anticipated with natural gas development projects.

Ongoing coal mining activities would continue to generate small amounts of criteria pollutants, including combustion products such as NO_2, CO, SO_2, VOCs, and $PM_{2.5}$, as well as fugitive dust emissions. Cumulatively, these mines have the potential to emit much larger quantities of criteria pollutants than the Proposed Action. The incremental contribution of emissions from the proposed exploratory drilling program is expected to be minimal and would be temporary (up to 3 years) in duration.

Cumulative air quality impacts associated with road construction or wildfires would depend on the timing and location of such events; cumulative impacts of the Proposed Action would be minor.

No unique or specific cumulative air quality impacts were identified for individual well sites.

3.1.4 Potential Mitigation Measures

Air quality impacts would be minor during the construction drilling, completion, and testing of the exploratory wells. The following additional mitigation would be implemented.

AQ-1: If air or gas drilling, the operator shall control the blooie line discharge dust by use of water injection or other acceptable methods. The blooie line discharge shall be a minimum of 100 feet from the blowout preventer and be directed into the blooie pit so that the cuttings and waste are contained in the pit.

3.2 Soils

3.2.1 Affected Environment

The study area for soils includes the well pad sites and new road spurs where surface disturbance would occur. The cumulative effects area comprises the same Proposed Action study area with the addition of surface disturbance associated with past, present, and future actions along the access roads and near the eight well sites.

Regionally, soils are highly variable based on the wide range of geology and topography, including mountain side-slopes, canyon lands, mesa lands, ridges, and river valley side slopes. The well pad sites are all located in areas with low to moderate slopes (6 to 15 percent). The well pad sites and associated new spur roads are contained within a total of four soil mapping units, consisting of soil series, families, or groupings. Information for soils was obtained from the Soil Survey of Grand Mesa – West Elk Area, Colorado (National Resource Conservation Service 1997), and from maps provided by the GMUG National Forests (USFS 2002a). Site-specific soils in the study area are described below.

The Powerline site, the WAPA maintenance road, Leon Lake #4, and Leon Lake #5 sites are located within the Wetopa-Wesdy soil complex. These deep (40 to 60 inches), well-drained soils are formed in residuum and colluvium from sandstone and shale parent material. The slope of soils in this complex generally ranges from 5 to 65 percent. The typical surface layer varies from clay loam to cobbly loam/very cobbly silty loam. The subsoil texture varies from clay to very cobbly clay, with the substratum varying from clay loam to very cobbly clay. The soil is classified as having high erosion potential in steep areas. Water erosion potential varies from low to high.

The Bull Park well site is located within the Delson sandy loam soil series. These deep (40 to 60 inches), well-drained soils are formed in stony alluvium located on fans and mesas. Slopes generally range from 3 to 20 percent. The typical surface layer consists of a stony loam. The subsoil texture is generally clay, with the substratum consisting of stony clay loam. Erosion due to wind is considered slight, with water erosion potential considered moderate.

The Oakbrush and Hubbard Creek well sites are located within the Herm-Fughes-Kolob family complex. These deep (40 to 60 inches), well-drained soils are formed in alluvium and residuum from sandstone and shale parent material. The slopes of these soils generally range from 25 to 40 percent. The typical surface layer varies from clay loam to loam. The subsoil texture varies from clay to stony clay loam. The substratum varies from clay to gravelly clay and loam to stony clay loam. Mass movement potential is classified as low to moderate. Water erosion potential varies from low to high.

The Hawksnest and Thompson Creek sites are located within the Fughes-Curecanti stony loam group. These soils are deep (40 to 60 inches) and well drained and are formed from sedimentary parent material in alluvium and landslide deposits. Slopes generally range from 3 to 65 percent. The typical surface layer consists of a stony loam. Subsoil varies from clay loam to very gravelly or very cobbly clay, and the substratum ranges from clay loam to very stony loam. Erosion due to wind is considered slight, with water erosion considered potentially high in areas with steep slopes.

The Coal Gulch Jeep Trail, which is the access for the Hawksnest and Thompson creek sites, crosses two soil series types. The majority of the road, approximately 3.1 miles, is located within the Fughes-Curecanti stony loam group. Approximately 0.3 mile of the road is located within the Torriorthents-Rock outcrop, sandstone complex. This complex consists of moderate to very steep soils and outcrop on mountainsides and at foot slopes. Based on field observations, the access road would lie in the Torriorthents soils. These soils are well drained and range in depth from 10 to over 60 inches. The surface layer typically consists of very stony loam. Because these soils are generally located at the bottom of slopes, as is the case at this specific location, large stones and high rock fragment content are common. Surface runoff is typically rapid in this soil type. However, the high content of stones and rock fragments in the surface helps prevent water erosion.

3.2.2 Environmental Consequences

3.2.2.1 Proposed Action

Impacts Applicable to All Sites

Under the Proposed Action, approximately 30.13 acres of soil would be directly impacted by construction of the well pads and new access spur roads and road upgrades (**Table 2-2**). Direct impacts to soils would include the removal of vegetation and temporary disturbance of topsoil and subsurface soil through the construction of the well pad sites and associated spur roads and the upgrade of existing roads.

The segregation and reapplication of surface soils could cause the mixing of shallow soil horizons, resulting in a blending of soil characteristics and types. This blending would modify physical characteristics including structure, texture, and rock content. Compaction due to construction activities at the pad sites and along access roads would reduce aeration, permeability, and water-holding capacity of the soils. An increase in surface runoff could be expected, causing sheet, rill, and gully erosion. These compaction effects would be minimized through the proposed reclamation plan.

Soil disturbance from construction and traffic use could result in short-term erosion. Wind erosion is not expected to occur on disturbed areas due to the soil types, surrounding topography, and the relatively dense vegetative communities surrounding the pad sites. The potential for water erosion ranges from "low" to "high" across the soil types encountered. Erosion potential has been reduced by locating the well sites and new roads in areas with slopes of less than 15 percent, which meets the USFS lease stipulations of locating well pads in areas with slopes less than 40 percent. Upon completion, these pad sites would be nearly level with short slope lengths. The new spur roads would be constructed at an average grade of 8 percent or less based on USFS standards, which would minimize potential erosion from surface runoff. Implementation of the proposed SWPPP and Grading and Hydrology Plan would provide additional safeguards against erosion. In addition, the design feature for access roads (e.g., no mud blading and restrict activities to approved locations) would minimize soil erosion. Based on the proposed erosion control procedures during construction as well as the project reclamation plan, it is anticipated that the impacts to soils would be of short-term duration and of relatively low magnitude.

Leaks or spills of saline water, hydrofracturing chemicals, fuels, and lubricants could result in soil contamination. Depending on the size and type of spill, the effect on soils primarily would consist of the potential loss of soil productivity. However, implementation of the project SPCC Plan would minimize the risk of such spills and would provide safeguards against soils contamination from spills. No significant impacts to soils from spills are anticipated.

Clearing and grading of the well pad sites could result in the reduction of slope stability, depending on the slope of the land at and adjacent to the well pad site. However, because the well pad sites are proposed on sites ranging from 6 to 15 percent slope and disturbance would be limited to the well pad itself, the potential for decreased slope stability due to construction would be minimal. Additionally, the construction of spur roads would be limited to slopes of less than 8 percent to safeguard against compromising slope stability. No significant impacts to slope stability are anticipated.

Site-specific Impacts

Powerline and Leon Lake #4 and #5. Soils at the Powerline site, the WAPA maintenance road, Leon Lake #4, and Leon Lake #5 sites are located in the Wetopa-Wesdy soil complex. Soils at these sites consist of a loam or cobbly loam surface with a clay or cobbly clay subsurface. Erosion potential is generally considered high within this soil type, especially on steep slopes. However, because the Powerline site is located on a slope of 11 percent, Leon Lake #4 on a slope of 8 percent, and Leon Lake #5 on a slope of 6 percent, the erosion hazard would be minimized. Additionally, implementation of the SWPPP and the Grading and Hydrology Plan would provide additional safeguards against erosion.

Bull Park. The Bull Park site is located in Delson sand loam soils. Soils at this site consist of a stony loam surface with a clay subsurface. Water erosion potential is generally considered moderate in this soil type. However, because the soil disturbance at the Bull Park well pad site would occur on a slope of approximately 14 percent, the water erosion hazard would be minimized. Additionally, implementation of the SWPPP and the Grading and Hydrology Plan would provide additional safeguards against erosion.

Oakbrush and Hubbard Creek. The Oakbrush and Hubbard Creek sites are located in the Herm-Fughes-Kolob family complex. Soils at these sites consist of clay loam to loam surface with a clay or stony clay subsurface. Mass movement potential is considered to be low to moderate, with a water erosion potential of low to high. However, because the Oakbrush site is located on a slope of 15 percent and the Hubbard Creek site is located on a slope of 12 percent, the erosion hazard would be minimized. Additionally, implementation of the SWPPP and the Grading and Hydrology Plan would provide additional safeguards against erosion.

Hawksnest and Thompson Creek. Soils at the Hawksnest and Thompson Creek sites as well as 3.1 miles (11.3 acres) of the Coal Gulch Jeep Trail and the Pilot Knob/Coal Gulch ATV trail reroute (0.09 acre) are Fughes-Curecanti stony loam. Soils at these sites consist of a stony loam surface with a gravelly or cobbly clay subsurface. Water erosion potential in this soil type is generally considered high on steeper slopes. However, because the soil disturbance at these well pad sites would occur on a slope of approximately 6 percent at the Hawksnest site and 7 percent at the Thompson Creek site, the water erosion hazard would be minimized. Steep cut slopes exist along the Coal Gulch Jeep Trail. Along these stretches where upgrades would be necessary, water erosion is likely. However, implementation of the SWPPP and the Grading and Hydrology Plan would provide safeguards against erosion along the road. Approximately 0.3 mile (1.1 acre) of the road is located within the Torriorthents soil type. The surface layer typically consists of very stony loam. Because this segment of the road is located at the bottom of a slope, large stones and high rock fragment content are common in the soil. Surface runoff is typically rapid in this soil type and could cause erosion in upgraded areas. However, the high content of stones and rock fragments in the surface would help prevent water erosion. Additionally, implementation of the SWPPP and the Grading and Hydrology Plan would provide safeguards against erosion along the road.

The Bull Park, Powerline, Oakbrush and Hubbard Creek sites are located in areas stipulated by CSU for moderate geologic hazards, which require analysis for specific effects. The soil types present, along with the topography and slopes, indicate minimal risk of geologic hazards to be a concern at these locations.

3.2.2.2 No Action

Under the No Action Alternative, no soil disturbance would occur from project-related construction activities and traffic on access roads. Existing and approved activities would continue.

3.2.3 Cumulative Impacts

Past, present, and future actions with the potential for cumulative soils impacts include existing natural gas development, continued coal mining and exploration, timber sales, road construction, agricultural activities, and wildfires. The cumulative impacts to soils would vary depending on the location and amount of disturbance and the sensitivity of specific soil types to erosion. Typically, soils impacts associated with past, present, and future actions would consist of erosion and soil compaction. Erosion control measures and reclamation would be required for most of these activities to reduce direct, indirect, and cumulative soils impacts.

The potential cumulative impacts identified above generally would be applicable to the eight proposed exploratory gas well sites. Based on the information presented in **Table 2-9**, which describes the nature, location, and timing of these actions, the following wells could contribute to temporary (up to several years) cumulative soils impacts until reclamation has been completed and vegetation re-established.

- Leon Lake #4 and #5 – Livestock grazing; public use of jeep trails and roads (FR 125, FR 127, and 127.1A); and GEC exploration at Spaulding Peak #1, including 1.1 acre pad and 0.5 mile of new road; and recompletion activities at Leon Lake #2 and abandonment of Leon Lake #1 could result in temporary cumulative soils impacts in the vicinity of these well sites. Continued public use of the roads along with project related traffic would contribute to compaction of soils comprising native surface roads (FR 127). Additional disturbance at the Spaulding #1 site (about 1 mile south and southeast of Leon Lake #4 and #5) would not contribute substantially to cumulative impacts in the area. Redisturbing the Leon Lake #2 site for recompletion purposes would not effect virgin soils. The Leon Lake #1 well would be plugged and abandoned and the site revegetated. This would not contribute to effects on soils.

- Powerline – Livestock grazing, road use of FR 701, timber clearing for the Stevens Gulch Personal Use Area and the Rifle-Curecanti Powerline, past clearcuts of 368 acres in the Alder Creek watershed, 860 acres in the Terror Creek watershed, and the drilling of 18 exploratory wells with road access under the Alder Creek Coal Exploration Lease could result in temporary cumulative soils impacts.

- Bull Park – Livestock grazing, public use of jeep trails, road use of FR 701, oakbrush control, the proposed 200-acre Terror Creek Green Oak Area timber management project; the 20-acre East Terror Timber Sale and Personal Use Firewood project; timber clearing for the Stevens Gulch Personal Use Area and the Rifle-Curecanti Powerline; past clearcuts of 368 acres in the Alder Creek watershed, 860 acres in the Terror Creek watershed; the drilling of 18 exploratory wells with road access under the Alder Creek Coal Exploration Lease; and GEC exploration at Stevens Gulch #1, including 1.1 acre pad and 0.5 mile of new road, could result in temporary cumulative soils impacts, but would have negligible effects to the area as a whole.

- Hubbard Creek and Oakbrush – Livestock grazing; outfitter guides; timber clearing for the Stevens Gulch Personal Use Area; upgrade of the Bowie mine including 1.8 miles of road upgrade, 5.4 miles of new road construction, 3 acres of drill pad disturbance, and 18 coal exploration holes; the proposed 2-acre disturbance for a coal exploration hole and associated road access by Oxbow Coal Exploration; and the proposed GEC exploratory well at Lone Pine #1, including 1.1 acre pad and 0.4 mile of new road, could result in temporary cumulative soils impacts at these well sites, but would have negligible effects to the area as a whole.

- Hawksnest and Thompson Creek – Livestock grazing, vehicle use and maintenance on Coal Gulch Road, the inactive Hawksnest Mine, the inactive Sanborn Mine, authorized coal exploration activities in approximately 8 sections, and all-terrain vehicle use on the Pilot Knob/Coal Gulch ATV Trail could result in temporary cumulative soils impacts.

Although the well sites could contribute to temporary cumulative soil impacts, by implementing erosion control measures and reclamation activities at the well sites and at the projects listed above, the extent and duration of cumulative soils impacts would be minimal.

3.2.4 Potential Mitigation Measures

Erosion impacts associated with potential damage to existing access roads would be mitigated by conducting a pre-construction road condition assessment and implementing a multi-party agreement for repairing road damage. These two mitigation measures (T-2 and T-3) are discussed in Section 3.12.4. Additional mitigation for soils include the following measures:

S-1: Design soil stockpiles to minimize risk of wind and soil erosion.

S-2: Activities may be curtailed during periods when the soil and/or road subgrade is saturated. This possible restriction would be determined by the responsible land management agency (BLM or USFS).

S-3: If a spill occurred, contaminated soil would be properly disposed of prior to backfilling and reclamation.

S-4: Revegetate disturbed soils by the end of the first growing season.

S-5: Use site preparation methods, which are designed to keep fertile, friable topsoil essentially intact.

S-6: Use of heavy construction equipment would be limited to times when the soil is least susceptible to compaction or rutting.

3.3 Geology and Minerals

3.3.1 Affected Environment

The study area for geology and minerals encompasses an area generally defined by T12S through T13S and R89W through R94W, excluding areas south of the North Fork of the Gunnison River. It also includes the southern portions of T11S through R89W and R94W. Some discussion refers to areas outside the defined study area in order to provide a regional overview of geology and mineral resources. This area applies to both the Proposed Action and cumulative effects area.

3.3.1.1 Geology and Physiography

<u>Geology</u>

The project is located at the southern edge of the Piceance Creek Basin, an intermountain basin that was formed in the Late Cretaceous through Tertiary time (65 to 1.6 million years ago). The basin is irregularly shaped and is 100 miles long from northwest to southeast (roughly from southwest Moffat County to northwest Gunnison County), 50 miles wide (roughly from Glenwood Springs to Grand Junction), and covers an area of 7,200 square miles (Murray et al 1977; Spencer 1995). The basin contains sedimentary rocks ranging in age from Cambrian to Tertiary (570 to 1.6 million years). The basin is bounded on the south and southwest by the Uncompahgre Uplift, on the north by the Uinta Mountains Uplift and Axial Basin Anticline, and on the east by the White River and Sawatch uplifts (Hettinger et al. 2000).

Geologic formations of interest in the study area consist of Tertiary and upper Cretaceous sedimentary units that form the bedrock of the area. The bedrock units dip 5 to 6 degrees to the north into the basin (Hettinger et al. 2000). These rocks are overlain by surficial deposits that consist of Quaternary alluvium, colluvium, landslide, and mudflow deposits (Dunrud 1989a,b). Tertiary volcanic rocks (basalt) occur on the northern edge of the study area. **Figure 3.3-1** is a stratigraphic chart that includes descriptions of the rocks and deposits in the project area.

The upper Cretaceous rocks consist of the Mancos Shale and the Mesaverde Formation. Tertiary rocks consist of the Wasatch, Green River, and Uinta formations. The Upper Cretaceous rocks were deposited in marine, nearshore marine, fluvial, and continental depositional environments (Hettinger et al. 2000). The coal-bearing rocks of the Mesaverde Formation largely were deposited in a coastal plain – deltaic setting. The Tertiary rocks were deposited in fluvial (stream) and lacustrine (lake) settings. The Tertiary lava flows that cap the Grand Mesa were more extensive when first deposited, but have been reduced in areal extent because of erosion (Chronic and Williams 2002).

Era	System	Unit Name	Member	Thickness (feet)	Description
Cenozoic	Quaternary (1.6 million years ago [mya])	Grand Mesa Formation (glacial till only)		Variable up to 250	Alluvium, colluvium, glacial till, landslide, and debris flow deposits derived from basalt, Uinta, and Green River formations.
	Tertiary (1.6 – 65 mya)	Igneous rocks		200 - 500	Volcanic basalt and gabbro occurring in dikes and flows.
		Uinta Formation		Not determined	Siltstone, sandstone, and claystone.
		Green River Formation		600 - 1,200	Marlstone, oil shale, and sandstone; upper part interfingers with the Uinta Formation and lower part interfingers with the Wasatch Formation. Fluvial and lacustrine in origin.
		Wasatch Formation		1,000 - 2,500	Mostly varicolored claystone and mudstone with localized sandstone lenses and limestone beds. Sandstones are often made up of volcanic material. Fluvial and lacustrine in origin. Landslides are common in the Wasatch.
Mesozoic	Upper Cretaceous (65 – 78 mya)	Mesaverde Formation	Ohio Creek Member	500 - 1,100	Interbedded sandstone, mudstone, and shale. Sandstone is fine- to coarse-grained and in places conglomeratic and can be up to 200 feet thick. Deposited in a fluvial (stream) environment.
			Barren Member	750 - 1,000	Interbedded sandstone, mudstone, and shale. Sandstones may locally be as much as 100 feet thick. Deposited in a continental environment. Named for general absence of coal seams.
			Coal-bearing Member (Cameo)	300 - 700	Sandstone, mudstone, shale, and siltstone with interbedded coalbeds up to 150 feet thick. Lenticular sands may be up to 40 feet thick. Deposited in coastal-plain and nearshore marine environment.
			Rollins Sandstone Member	80 - 200	Interbedded sandstone, mudstone, and silty sandstone. Grades into the Mancos Shale at base of member. Deposited in nearshore marine environment.
			Cozzette Member	50 - 150	Fine- to very fine-grained sandstone, siltstone, and shale. Separated from main part of Mesaverde by a tongue of the Mancos Shale. Deposited in nearshore marine environment.
		Mancos Shale		4,000 - 4,500	Shale and mudstone, with bentonite clay and thin sandy limestones in the Cedaredge-Hotchkiss area. Deposited in marine environment.

Sources: Dunrud 1989a,b; Ellis and Freeman 1984; Ellis et al. 1987; Hettinger et al. 2000; and Yeend 1969.

Figure 3.3-1 Stratigraphic Column and Rock Unit Descriptions

The unconsolidated deposits include a variety of materials deposited by streams, but they also include large volumes of material that were eroded and transported through mass wasting by landslides and debris flows. These deposits are composed of clay, silt, sand, gravel, and boulders. There are older deposits of glacial outwash materials that were deposited by Pleistocene (Ice Age) glaciers. The material was largely derived from the Wasatch and Green River formations but also includes numerous boulders of basalt.

Physiography

The study area is located on the northeastern part of the Colorado Plateau physiographic province (Howard and Williams 1972). The topography of the province is characterized by mesas, badlands, and canyons. The study area is located on the southern edge of the Grand Mesa, a prominent topographic feature of northwestern Colorado; elevations rise from less than 5,000 feet amsl along the Gunnison River and North Fork of the Gunnison River to over 10,000 feet amsl at the top of the mesa.

The study area is drained by south-flowing tributaries of the North Fork of the Gunnison River, which flows in a general southwesterly direction. The steep elevations on the south side of Grand Mesa have allowed the south-flowing streams to erode deeply incised drainages along the edge of the mesa. The project facilities would be located at elevations ranging from 7,800 feet (Hubbard Creek) to 8,980 feet (Leon Lake #4) amsl on less steep terrain away from the edge of the severe slopes and steep drainages at the edge of the mesa.

3.3.1.2 Geologic Hazards

Landslides

The study area is typified by the presence of landslides. Landslides involve the mass movement of earth materials down slopes and can include debris flows, soil creep, and slumping of large blocks of material. The mass downslope movement of earth materials also is referred to as mass-wasting (Gary et al. 1974). There are many areas in the Colorado Plateau that are susceptible to landslides because of mesas that are capped with resistant rock that overlie weaker, more easily erodeable rocks (Radbruch-Hall et al. 1980). The south side of the Grand Mesa, in addition to being capped by a layer of resistant basalt, has very steep slopes. In addition, the Tertiary rocks that underlie the basalt are highly erodeable. The following information summarizes the project component locations with respect to identified landslide deposits or landslide-prone bedrock.

Leon Lake #4 and Leon Lake #5 Sites. These proposed locations are on glacial till deposits that are Pleistocene in age (Yeend 1969). These deposits are composed of unsorted gravel, sand, and silt-loam, with abundant pebbles that are largely composed of basalt. The bedrock at the Leon Lake #4 and #5 sites is the Wasatch Formation, but landslide deposits are not indicated at these locations. The slopes at the Leon Lake #4 and #5 sites are approximately 8 and 6 percent, respectively.

Bull Park and Powerline Sites. The proposed Powerline well pad location is located on Holocene and Pleistocene landslide and mudflow deposits (Ellis and Freeman 1984; Ellis et al. 1987; Dunrud 1989a). These deposits consist of a poorly sorted mixture of clay, silt, sand, gravel, and boulders that were deposited by various combinations of slumping, sliding, and flowing. The surface expression of these deposits is characterized by cracks and scarps in the upper part and hummocky topography and local closed depressions near the base of slide areas (Dunrud 1989a). Composed of claystone and mudstone with local lenses of sandstone, volcanic sandstone, and basal conglomerate, the Wasatch is a Tertiary age formation commonly containing small, unmapped Quaternary landslides, alluvium, colluvium, and other unconsolidated deposits. Large landslides and mudflows are common in Wasatch claystones on steep slopes (Ellis et al. 1987; Dunrud 1989a). The Bull Park site is located on an outcrop of the Wasatch Formation. The Bull Park site is located in a geologic hazard area defined by Junge (1978) as a "slope failure complex" or an area formed by various types of mass-wasting processes such as landslides, mudflow, rockfalls, and soil creep." The Powerline is not in the area mapped by Junge (1978), but since it is located on the same surficial materials as Bull Park, presumably it is located in a potential landslide area. The exact type of mass-wasting and degree of hazard at the locations only can be determined by site-specific surveys. The slopes at the Bull Park and Powerline sites are approximately 14 and 11 percent, respectively.

Hubbard Creek and Oakbrush Sites. The proposed well pad locations are underlain by the Wasatch Formation. The characteristics of this formation are discussed above for the Bull Park site. The Hubbard Creek and Oakbrush sites also are located in a geologic hazard area defined by Junge (1978) as a "slope failure complex area" as described above. The exact type of mass-wasting and degree of hazard at the locations can only be determined by site-specific surveys. The slopes at the Hubbard Creek and Oakbrush sites are approximately 12 and 15 percent, respectively.

Thompson Creek and Hawksnest Sites. The proposed Hawksnest well pad is located on unconsolidated Pleistocene deposits composed of basalt boulders and Wasatch Formation materials (clay, silt, and sand). These materials are heterogeneous to moderately well sorted and range from unstratified to well stratified. The degree of sorting and stratification commonly control susceptibility to erosion and mass-gravity movements. These deposits typically are stable and resistant to erosion on steep slopes and on water-bearing zones, which consist of stratified sand, gravel, and boulders. However, the materials may be unstable and easily erodeable on steep slopes that contain little or no water and where material is heterogeneous, unstratified, and clay is the dominant component (Ellis et al. 1987; Dunrud 1989a). The Hawksnest and Thompson Creek sites are located in a geologic hazard area defined by Junge (1978) as a "slope failure complex area" as described above. The exact type of mass-wasting and degree of hazard at the locations only can be determined by site-specific surveys. The Thompson Creek site is located on an outcrop of the Wasatch Formation. Slopes at the Thompson Creek and Hawksnest sites are approximately 7 and 6 percent, respectively.

Seismicity and Faults

Earthquakes occur when energy is released when blocks of the earth's crust move along areas of crustal weakness or faults. Fault movement can occur in response to a variety of causes, natural and anthropogenic. Among natural causes are uplift caused by upward movement of magma and compression or tension resulting from large-scale movements of the crust. Among anthropogenic causes of seismic events are reservoirs, deep well injection of fluids, and blasting from mining.

Historically, recorded earthquakes in Colorado go back to 1870 (U.S. Geological Survey [USGS] 2001). Since then, many small earthquakes either have been felt by persons or recorded by seismograph networks. The largest earthquake in Colorado occurred in December 1882 in the vicinity of Rocky Mountain National Park, with an estimated intensity of 6.2 Richter scale magnitude that is considered a "strong" earthquake. No earthquakes of similar magnitude have been recorded in Colorado since then (USGS 2001).

There have been several minor earthquakes in the study area along the Delta-Gunnison County line north and south of the North Fork of the Gunnison River (Colorado Geological Survey 2003; USGS 2001). Minor earthquakes also have been recorded in nearby areas such as Carbondale, Aspen, Glenwood Springs, Crested Butte, and Montrose. All of these earthquakes were considered minor to very minor (less than 3.9 on the Richter scale). Earthquakes up to 2.8 on the Richter scale have occurred in the study area due to coal mine collapses (Dunrud 2003).

An active fault is one that is defined as having movement or displacement within the last 11,000 years (California Division of Mines and Geology 1997). A potentially active fault is one in which there is evidence of movement within the last 1.6 million years before present (or the beginning of the Quaternary). No active or potentially active faults have been determined in the study area; however, a number of Quaternary faults have been mapped to the southwest of the area, the closest ones in western Delta County (Widmann et al. 1998). The faults are part of a series of faults that occur on the northeastern flank of the Uncompahgre Uplift. Timing of movement on the faults is not precisely known, but it is believed to be in Quaternary time (less than 1.6 million years before present).

Other faults have been mapped in the study area (Ellis and Freeman 1984; Ellis et al. 1987; Dunrud 1989a,b). These were mapped on the Rollins Sandstone Member of the Mesaverde Formation based on drill hole information. The faults are normal faults and generally trend north and south. Some of the faults as mapped appear to have evident surface expression on the Mesaverde outcrops, while Dunrud (1989a,b) infers fault traces in the Wasatch Formation and in the surficial materials covering the Mesaverde outcrops. It is not certain whether these faults actually cut the unconsolidated Quaternary materials. **Table 3.3-1** summarizes the locations of faults with respect to the proposed well locations.

Movement on faults generates energy that can result in ground motion in the vicinity or even many miles from the fault. Whether ground motion is felt at any particular locality depends on the distance from the fault, the type of earth materials that the seismic energy must travel through, and the types of deposits at the locality. The project area is located in an area that is expected to have a small risk of severe ground motion (Frankel et al. 1997).

3.3.1.3 Mineral Resources

The primary leaseable minerals and mineral resources in the Piceance Basin are natural gas and coal. The natural gas resources are largely in the Upper Cretaceous and Tertiary rocks, and the coal resources primarily are found in the Mesaverde Formation (Spencer 1995; Hettinger et. al. 2000). Natural gas has been produced in the Piceance Basin since 1890, and coal production has occurred since the late 1800s. Portions of the following counties are within the Piceance Basin: Delta, Garfield, Gunnison, Mesa, Moffat, and Rio Blanco.

Table 3.3-1
Summary of Faults

Location	Distance and Direction to Nearest Fault	Source
Leon Lake #4	Surface Creek Fault possibly greater than 1.0 mile east, no data to confirm if fault continues north from Cedaredge area.	Dunrud (1989b)
Leon Lake #5	Surface Creek Fault possibly greater than 1.0 mile east, no data to confirm if fault continues north from Cedaredge area.	Dunrud (1989b)
Bull Park	Less than 500 feet southeast.	Dunrud (1989a)
Powerline	No faults identified within 1.0 mile of site.	Dunrud (1989a); Ellis and Freeman (1984)
Hubbard Creek	2,600 feet south.	Ellis et al. (1987)
Oakbrush	Two normal faults within 1,000 feet.	Ellis et al. (1987)
Hawksnest	Normal fault approximately 2,500 feet southwest.	Ellis et al. (1987)
Thompson Creek (bottom hole location)	Normal fault approximately 4,000 feet west.	Ellis et al. (1987)

Gas production in the Piceance Basin has been from sandstones and coal seams. Coalbed natural gas has not been an important contributor to total gas production. Coalbed gas production peaked in 1992 with production in Garfield, Mesa, and Rio Blanco counties totaling nearly 4.7 billion cubic feet (BCF) (Lawson and Hemborg 1999). The total gas production in 1992 in those counties plus Gunnison County was 62.4 BCF, and coalbed gas contributed less than 8 percent of the total production. Gas reservoirs (sandstone and coalbeds) in the Piceance Basin are characterized by low permeability (i.e., a measure of how well rocks transmit fluid) and generally require hydraulic fracturing stimulation to produce commercial quantities of gas.

The Mesaverde Formation, which produces from sandstones and coals, is an important gas producing formation in the Piceance Basin. North of the project area, Mesaverde gas production from sandstones started in the 1950s with discoveries of fields such as Plateau, Divide Creek, Rulison, Mamm Creek, and Buzzard Creek (Dunn 1972). The sandstone gas reservoirs that were produced were often typified by low porosity and permeability and for many years, production from these rocks was not commensurate with the estimated gas resource. Porosity or void space is that portion of the rock that is not taken up by the mineral matrix of the rock. The porosity in hydrocarbon reservoirs contains varying amounts of fluid that may consist of oil, gas, and water. Permeability is a rock property that is a measurement of the ability of rock to transmit fluid. Low porosity and permeability sandstone gas reservoirs are referred to as “tight sands” and are considered to be unconventional reservoirs. Because of the extremely low permeability, Mesaverde sandstone reservoirs are not likely to produce large amounts of water.

Coalbeds by definition also are considered unconventional reservoirs (USGS National Oil and Gas Assessment Team 1995). Coalbed natural gas production is well established in the south-central and northeast portion of the Piceance Basin (Tyler et al. 1995). Coalbed natural gas began to be produced in the 1980s and by the 1990s had been established as a significant resource base. The coalbeds in the Piceance

Basin also have exhibited low porosity and permeability (Seccombe and Decker 1986) and therefore are not expected to produce much water. With the exception of the Divide Creek area, potential water production is below 100 bpd (4,200 gallons per day) (Tyler et al. 1995).

Some of the older Mesaverde gas fields mentioned above have been revived in the last decade because of advances in completion techniques. Instead of producing from a few isolated reservoirs in a well, the standard practice is to hydrofracture several intervals of 400 to 500 feet that may contain a number of potential reservoirs, with 3 to 5 intervals per well (Hemborg 2000). This practice maximizes the amount of gas that can be recovered from a given well and the intervals can contain sandstones and coals. Based on Mesaverde production in other parts of the Piceance Basin, sandstones and coal seams are prospective gas reservoirs. Neither coal seams or "tight" sands would be considered "conventional" reservoirs. Prospective sandstones and coalbed reservoirs in the proposed project area are expected to have properties similar to reservoirs in other Piceance Basin Mesaverde reservoirs: low porosity and permeability and relatively low potential water production rates.

The USGS has conducted an assessment of oil and gas resources of the Mesaverde rocks in the Piceance Basin, and the results of the assessment have recently been released (Johnson and Roberts 2003). The USGS assessment involved a methodology that considers the Mesaverde as a total petroleum system (TPS). A TPS is "a mappable entity encompassing genetically related petroleum that occurs in seeps, shows, and accumulations (discovered or undiscovered) that have been generated by a pod or closely related pods of mature source rocks." Within the TPS are assessment units. An assessment unit is defined as "a mappable volume of rock within a total petroleum system that encompasses accumulations (discovered or undiscovered) that share similar geologic traits." Assessment units may contain either conventional or unconventional reservoirs. The dominant hydrocarbon resource of the Mesaverde TPS is natural gas; very little oil is produced relative to gas (Johnson and Roberts 2003). The Mesaverde TPS of the Piceance Basin has been divided into four assessment units. Two of the defined assessment units underlie the project area; the Uinta-Piceance Basin Conventional Gas and the Mesaverde Group Coalbed Gas Assessment Units.

The Uinta-Piceance Basin Conventional Gas Assessment Unit has an estimated mean of 0.066 trillion cubic feet (TCF) of undiscovered gas resource from sandstones in the Wasatch Formation and from Mesaverde sandstones located along the basin margin areas. The Uinta-Piceance Basin Conventional Gas Assessment Unit is considered to be a "frontier" play because only two fields have been identified that produce from the unit. The Mesaverde Group Coalbed Gas Assessment Unit includes coals up to 7,000 feet deep in the Piceance Basin and includes the coalbeds that produce in the Grand Valley and Parachute Fields. The Mesaverde Group Coalbed Gas Assessment Unit has an estimated mean of 0.4 TCF of undiscovered gas resource (Johnson and Roberts 2003).

Within the study area, as defined in Section 3.3.1, 25 wells have been drilled for natural gas (Appendix F, **Table F-1**). Twenty-two wells have been classified as dry and abandoned or plugged and abandoned, two are classified as temporarily abandoned, and one is shut-in (COGCC 2003; IHS Energy Services 2003). The closest commercial gas production is from the Coal Basin gas field in northwestern Gunnison County in T11S, R90W about 8 to 10 miles north of the closest Proposed Action drilling (COGCC 2003; Wray et al. 2002). Production for the Coal Basin gas field averaged 14.4 million cubic feet of gas per year from 1999 through 2002. The field also produces small amounts of gas condensate and water (14 and 241 barrels respectively for 2002) (COGCC 2003). This field produces from sandstone reservoirs. The nearest oil production is from the Crawford Field in the southeastern corner of Delta County in T51N, R6W (New Mexico Principal Meridian).

The GMUG Oil and Gas Final EIS forecasted that 24 wells would be drilled on the Grand Mesa and Gunnison portions of the national forest between 1991 and 2005 under the Reasonably Foreseeable Development Scenario. Since the publication of the Final EIS in 1993, four wells have been drilled in these areas. The exploration drilling proposed in this project is within the forecast.

Coal is the principal mineral produced in the area from several mines in Delta and Gunnison counties in the North Fork of the Gunnison River valley in an area called the Somerset Coal Field (Tremain et al. 1996). The mines produce high-volatile B and C bituminous coal from a number of seams in the Cameo or Coal-bearing Member of the Mesaverde Formation (**Figure 3.3-1**). Four underground mines active in 1995 produced over 7.3 million tons of coal. There also are numerous abandoned mines along the Mesaverde outcrop in the study area (Widmann et al. 2002). Information (Colorado Division of Minerals and Geology [CDMG] 2003) indicated that there are still three active underground coal mines in the Somerset Coal Field as of February 2003.

Other mineral resources of lesser importance are sand and gravel, dimension stone, and clay (Widmann et al. 2002). In numerous places in the study area, sand and gravel are mined in alluvial and glacial deposits. Dimension stone also is quarried in T13S, R90W, in the North Fork of the Gunnison River valley northeast of Paonia.

There are no deposits of locatable minerals (metallic mineral resources) in the study area or in the immediate vicinity (Widmann et al. 2002).

3.3.2 Environmental Consequences

3.3.2.1 Proposed Action

The following information describes potential project impacts on geology and minerals. Several of these topics (i.e., landslide, faults, and mine workings) also are discussed in groundwater impacts in Section 3.4.2.2.

__Landslides__

Impacts Applicable to All Sites. Landslide impacts are not applicable to all sites. The Leon Lake #4 and Leon Lake #5 are not located on mapped landslide deposits and there are no lease stipulations concerning geologic hazards. Therefore, landslides and mass-wasting are not expected to pose potential impacts for these two locations.

Site-specific Impacts. The following impacts are specific to particular sites or their associated road spurs. Several project elements are located in areas with a potential for landslides and mass-wasting to occur. In addition to being located in areas mapped as landslide or mass-wasting deposits (Ellis and Freeman 1984; Ellis et al. 1987; Dunrud 1989a), the Colorado Geological Survey (Junge 1987) designated these areas as "slope failure complex areas." Wells on pads and associated roads that are built on unstable materials would be subject to damage or loss due to large mass-wasting events.

Bull Park, Powerline, Hubbard Creek, Oakbrush, Thompson Creek, and Hawksnest. These well sites are located either on materials that contain landslides deposits or are in areas that have been defined as "slope failure complex areas." As discussed in Section 2.1.2.12, these wells are located in areas where a CSU stipulation is in effect for moderate geologic hazards. Location of the wells in the area of CSU for geologic hazards requires analysis and mitigation of site-specific hazards by an interdisciplinary team of specialists (potentially including, geotechnical, soils, road engineers, oil and gas specialist, and reclamation specialist). The CSU areas in relation to the particular sites are shown in Appendix D.

Through the NOS process, these locations were sited to ensure negligible effects from landslide and mass-wasting hazards. No evidence of landslides or mass wasting was observed at the locations carried forward in the Proposed Action. Given the site layout, and the slopes and soils present, the potential for disturbance associated with the exploration wells to cause landslides or other earth movements is very unlikely.

Hawksnest. The site is located in a "slope failure complex area." The site location is in an area where no impacts from such hazards are expected.

Seismic Hazards

Impacts Applicable to All Sites. Fault movement and ground motion from earthquakes could cause damage to roads, and other facilities and could induce hazards of landslides and mass-wasting.

Natural Seismic Hazards. There is a low potential for a natural seismic event to initiate strong ground motions in the area. No active faults (movement within the last 11,000 years) have been determined to be in the vicinity of the project area. Based on the foregoing, impacts from natural seismicity are expected to be negligible.

Induced Seismic Hazards. There is a concern that injection of fluid in the subsurface would result in induced seismic activity. In the reported or suspected cases of induced seismicity from the injection of fluids, large amounts of fluid were injected over an extended period of time. For this project, the fluids would be injected only during the completion process during treatment and hydraulic fracturing. The fluid volumes to be injected for each well (an estimated 0.33 acre-feet or 107,547 gallons) are relatively small and amount to a one-time injection event. This compares to one injection disposal well in the Trinidad coalbed gas field operations that injects an average of 25 acre-feet (8,274,000 gallons) per month (COGCC 2003). Furthermore, the horizontal extent of hydraulically induced fractures are not expected to reach faults from any of the locations. However, if a fault is encountered during hydraulic fracturing operations, monitoring would be performed as discussed in Section 3.3.4. There would be no injection disposal of produced water or completion fluids in the affected environment area. No impacts are expected from induced seismic hazards.

Site-specific Impacts. No specific or unique seismic impact information has been identified for the well sites and associated roads.

<u>Other Potential Geological Hazards</u>

Impacts Applicable to All Sites. Fluid withdrawal in oil and gas operations has been known to cause surface subsidence. The subsidence has occurred in areas like the Gulf Coast where the fluid in the pore spaces of the rock provides partial support of the rock matrix in partially consolidated or unconsolidated strata. Withdrawal of fluids causes compaction of the formation that in turn may cause the surface above the withdrawal site to subside. The surface subsidence can cause damage to roads, structures, utilities, and alter drainage patterns. However, the rocks of the Mesaverde Formation are well cemented and not partially supported by the fluid contained in the pores of the rocks. Withdrawal of fluids is not expected to result in compaction of the producing formation and resultant surface subsidence. Fluid withdrawal would not cause other effects such as earthquakes or landslides.

Another potential impact is the seepage of methane to the surface. The seepage of methane could result from the dewatering of coal seams where the influence of dewatering extends to the outcrop. Methane seepage to the surface could have effects on plants and groundwater as well as present a fire hazard. In the case of the proposed project, the potential impacts of methane seepage to the surface are negligible since the area of dewatering for all the proposed wells is not expected to extend to the outcrop. As can be seen in the geologic cross sections in Appendix I, even assuming a drainage radius of 2,100 feet for each well with a resulting drainage area of 320 acres, that radius of influence would not reach the outcrop.

Site-specific Impacts. No other specific or unique geologic hazard impact information has been identified for the well sites and associated roads.

<u>Mineral Resources</u>

Impacts Applicable to All Sites.

<u>Natural Gas Development.</u> Successful exploration may result in the extraction of natural gas resources. The estimated future recovery is not known at this time. The natural gas would be permanently removed from the strata.

Site-specific Impacts.

<u>Resource Recovery Conflicts.</u> Drilling of natural gas wells may potentially interfere with underground coal mining resulting in the loss of mineable coal, interference with mining operations, and present health and safety concerns.

As described in Section 2.1.12, the Bull Park, Powerline, Oakbrush, Hubbard Creek, Hawksnest, and Thompson Creek proposed wells are within the Paonia-Somerset KRCRA where the overburden over the B-Seam of the Mesaverde coal is less than 3,500 feet. The KRCRA is to be managed primarily for the exploration and extraction of coal resources. The leases at these proposed locations have stipulations that require oil and gas operators to consult with coal mine operators for the orderly development of the resources.

The following impacts are specific to particular well sites or their associated new spur roads:

- Bull Park. The proposed site is located within the KRCRA, but no impacts from coal mining conflicts are expected since there are not coal mine workings or coal exploration permits in close proximity to the location. Coal exploration permits issued to Bowie Resources are located just to the south of the proposed location in T13S, R91W (CDMG 2003). The proposed gas well location does not appear to be in conflict with coal exploration permit areas.

- Powerline. The proposed site is located within the KRCRA, but no impacts from coal mining conflicts are expected since there are not coal mine workings or coal exploration permits in close proximity to the location.

- Oakbrush. The proposed site is located within the KRCRA, but no impacts from coal mining conflicts are expected since there are not coal mine workings in close proximity to the location. The location of the Oakbrush site is within an area that is part of a federal coal exploration license. The proposed gas well location lies within 1 mile of 3 approved coal exploration holes. These holes have been eliminated from the coal exploration program and will not be drilled.

- Hubbard Creek. The proposed site is located within the KRCRA, but no impacts from coal mining conflicts are expected since there are not coal mine workings in close proximity to the location. The location of the Hubbard Creek site is within an area that is part of a federal coal exploration license. The well location also lies within 1 mile of 3 approved coal exploration holes. These holes have been eliminated from the coal exploration program and will not be drilled.

- Thompson Creek. The proposed site is located within the KRCRA and the surface location is about 600 feet north of the abandoned Sanborn Creek Mine workings, but the bottomhole location is 2,800 feet north of the workings. Since the mine is abandoned, no conflicts with coal mining are expected. Coal exploration permits issued to Oxbow Mining and Mountain Coal Company are located just to the south of the proposed location in Sections 7, 8, and 10 in T13S, R90W (CDMG 2003). The proposed gas well location does not appear to be in conflict with coal exploration permit areas.

- Hawksnest. The Hawksnest site is about 1,200 feet north and 500 feet west of the abandoned Sanborn Creek Mine workings. The area is part of the Sanborn Creek Mine, which is owned by GEC. Mining of the final longwall block in the mine was completed in February 2003. Equipment is being removed from the mine and it could be sealed by July 2003. Since the mine is abandoned, no conflicts with coal mining are expected. Coal exploration permits issued to Oxbow Mining and Mountain Coal Company are located just to the south of the proposed location in Sections 7, 8, and 10 in T13S, R90W (CDMG 2003). The proposed gas well location does not appear to be in conflict with coal exploration permit areas.

Additional Geology/Operation Issues

The following information addresses additional issues relative to operations and gas resources, as identified in Section 2.3.1.

- This is a CBM project and not conventional natural gas.

Sandstone and coals of the Mesaverde Formation are proposed as targets for drilling and testing (**Figure 2-5**). Although the USGS oil and gas resource assessment (Johnson and Roberts 2003) would consider the sandstone targets in the project area to be conventional reservoirs, they are still expected to have very low permeability. By definition, coalbeds are considered unconventional reservoirs (USGS National Oil and Gas Assessment Team 1995). According to the BLM, a gas well must be completed exclusively in a coalbed to be properly termed a CBM well. Based on this, and the fact that the exploration drilling targets both sandstone and coal layers of the Mesaverde Formation, this proposal for exploration drilling cannot be termed as solely CBM.

- Concern with well density.

When a gas discovery is made, a well spacing pattern must be established before development drilling begins. This Proposed Action is for exploration drilling, not development. Well spacing is regulated by the COGCC and BLM on federal lands. Factors considered in the establishment of a spacing pattern include reservoir data from the discovery well including porosity, permeability, pressure, composition, and depth. Other information pertinent to determining spacing includes well production rate, fluid ratios (gas/water) in the production stream, and the economic effect of the proposed spacing on recovery. Spacing for development gas wells is generally from 160 to 640 acres per well, but spacings of 20 to 40 acres are becoming more common, especially in low permeability reservoirs. Spacing requirements can pose problems in selecting an environmentally sound location. Reservoir characteristics and the drive mechanism determine the most efficient spacing to achieve maximum production. If an operator determines that a different spacing is necessary to achieve maximum recovery, the state and federal agencies may grant exceptions to the spacing requirements. Exceptions also may be obtained if the terrain is unsuitable, provided no geologic or legal problems are encountered. As the Proposed Action is for exploration drilling not development, the data discussed above are not available and would be collected during testing.

- Indicate geologic basis and criteria for well site locations.

The specific geologic basis for selection of particular drill sites is of necessity sometimes a proprietary process so the specific reasons for the selection of the proposed drill sites is considered confidential (43 CFR 3160). However, the selection process in general is based a number of factors, some of which are not necessarily geological. Selection of drill sites based on geology entail the analysis of many types of information that can include, but is not necessarily limited to, data from previous wells, information from published geological reports and maps, aerial photographs and other remote sensing imagery, and geophysical surveys. Non-geologic factors in selection of drill sites include well spot and spacing requirements established by rule or order of the COGCC, by lease stipulation, and topography.

- Proper fracing [sic] and design must be used.

Optimization of hydraulic fracturing is driven by economics (Howard and Fast 1970). Although it has been proven that hydraulic fracturing can economically enhance well production, it must be accomplished efficiently. A number of factors must be considered including, but not limited to, formation characteristics, fracturing fluid properties, cost of materials, estimated reserves, and how stimulation could incrementally enhance those reserves. The hydraulic fracturing conducted on the proposed wells would have to take into account those factors and any site-specific factors in order to be done efficiently and be protective of the environment. Bigger is not always better when considering cost-effective hydraulic fracturing. Fractures that extend too deep into the formation may not create the expected reservoir enhancement. The operator, in cooperation with the service company that would perform the fracturing job, would devise a fracturing plan that would maximize productivity and yet be cost effective and protective of non-productive strata. As part of the downhole and technical engineering portion of the APD, the fracing plan will be reviewed by a BLM petroleum engineer to ensure proper design is used before final APD approval is given (see Section 1.4).

- Proper cementing and casing.

Refer to Section 2.1.1.2. As part of the downhole and technical engineering portion of the APD, the cementing and casing plan will be reviewed by a BLM petroleum engineer before final APD approval is given (see Section 1.4).

- Need to test formations near wellbore.

Formation evaluation would take place as a result of drilling the proposed wells.

- Explain vast differences between CBM and conventional gas wells.

A major difference between gas production from coal seams and gas production from other reservoirs (conventional or non-conventional) is that often coalbed wells have to be produced for a period of time before it can be determined whether a well is commercial. If it is determined that there is commercial potential for coalbed natural gas, the typical route to development is to begin to produce the wells in order to draw off the water to determine if the coal seams are able to gas at commercial rates. Often a pilot project will be proposed in which a few wells are drilled at an adequate spacing to test the effectiveness of pumping water. Several wells are drilled and pumped to the point until significant gas is produced. If the production proves to be economical, then the operator will propose to drill a number of wells that will most efficiently drain the gas from the coal. Several aspects of CBM are unique, but most are similar or identical to conventional oil and gas activities. The technology and methods utilized to drill and complete the wells are essentially the same as standard practices in the oil and gas industry. The drilling method, blowout prevention equipment, and casing programs are nearly identical to those used in conventional operations. The typical casing job is modified slightly so that sufficient cement can fill the entire space around the casing and restrict movement of fluids.

This Proposed Action is for exploration drilling. Based on the lack of specific data on gas reservoir characteristics for the Southern Piceance Basin, it is not possible to predict if development of a gas field would occur in this area. If exploration drilling and testing discover a producible field, plans for development would have to be submitted and subject to a NEPA analysis before future production could occur.

- Conventional wells are devoid of water and flow under their own pressure.

There are two major classifications of hydrocarbon accumulations: conventional and unconventional. Conventional accumulations are those that are "bounded by a down-dip water contact, from which"…hydrocarbons…"can be extracted using traditional development practices, including production at the surface from a well as a consequence of natural pressure within the subsurface reservoir, artificial lifting of oil from the reservoir to the surface where applicable, and the maintenance of reservoir pressure by means of water or gas injection" (USGS National Oil and Gas Assessment Team 1995). Conventional reservoirs can produce varying amounts of oil, gas, and water with water being the main waste product produced in the upstream oil and gas industry.

Unconventional accumulations are those that are not produced by conventional production practices (USGS National Oil and Gas Assessment Team 1995). Types of unconventional accumulations include coalbed natural gas, "tight" gas sandstones, and basin-centered (or continuous-type) gas accumulations. Coalbed natural gas, tight sandstones, and basin-centered gas accumulations, are potential hydrocarbon settings in Rocky Mountain basins including the Piceance Basin.

- Disclose the amount and types of [chemicals and fuels] to be used.

A list of chemicals for project activities is provided in Appendix C, and discussed in Section 3.14.

3.3.2.2 No Action

Under the No Action Alternative, project-related impacts to geology and mineral resources, as described for the Proposed Action, would not occur.

3.3.3 Cumulative Impacts

The proposed project would have no incremental cumulative effect on seismicity, faults, landslides, or coal mining. The project would contribute immediately to a slight permanent reduction in gas reserves due to venting and flaring.

The potential cumulative impact identified above generally would be applicable to the eight proposed exploratory gas well sites. Based on the information presented in **Table 2-9**, which describes the nature, location, and timing of these actions, the following well sites could be subject to temporary site-specific cumulative impacts to gas resources.

- Leon Lake #4 and #5. The Leon Lake Gas #1 will be plugged and abandoned and the site will be reclaimed. The Leon Lake #2 will be re-drilled and completed. The Spaulding Peak #1 is a proposed well on fee minerals located about 0.7 mile south of the proposed Leon Lake #5.

- Bull Park. The Stevens Gulch #1 is a proposed well on fee minerals located about 2 miles southwest of the proposed Bull Park site. Due to the distance between these exploration wells, the cumulative impacts on the gas resource would be negligible.

- Hubbard Creek and Oakbrush. Lone Pine #1 is a proposed well on fee minerals located about 2 miles southwest of the proposed Hubbard Creek and Oakbrush sites. Due to the distance between these gas exploration wells, the cumulative impacts on the gas resource would be negligible. The locations of the Oakbrush and Hubbard Creek proposed wells are within 1 mile of three approved coal exploration holes on Bowie Resources Limited Alder Creek federal Coal Exploration License. To date, the three coal exploration holes have not been drilled, and may not be under the life of the exploration license, which expires in 2004. If they are drilled, they would result in surface disturbance that would be reclaimed the same season. These holes are located on the opposite site of the Hubbard Creek drainage. Due to the immediate reclamation required, and the topographic and physical separation between the Oakbrush and Hubbard Creek proposed gas wells, and the three coal exploration holes, the cumulative impacts of these activities would be minimal.

3.3.4 Potential Mitigation Measures

No mitigation measures have been identified for geological resources.

3.4 Water Resources

3.4.1 Affected Environment

3.4.1.1 Surface Water

The study area for surface water resources includes three watersheds with perennial drainages (Surface, Terror, and Hubbard creeks) and two watersheds that contain intermittent drainages that encompass the well sites and new road spurs (**Table 3.4-1**) and are part of the North Fork of the Gunnison River Basin. The cumulative effects area includes the middle and lower portions of the watersheds that are associated with these drainages and the North Fork of the Gunnison River. The following information summarizes surface flows and water quality/uses for these streams. Baseline surface water data come primarily from Wright Water Engineers, Inc. (WWE 2003a) and are considered sufficient for characterization of the project area.

Table 3.4-1
Drainage Locations of Well Sites and Access Roads

Well Site	Drainage Location	Type of Drainage
Leon Lake #4	Surface Creek	Perennial
Leon Lake #5	Surface Creek	Perennial
Powerline	Upper portion of East Fork Terror Creek and unnamed intermittent tributary to Iron Point Gulch (tributary to Hubbard Creek)	Perennial
Bull Park	Unnamed tributary to West Fork Terror Creek	Perennial
Hubbard Creek	Unnamed tributary to Hubbard Creek	Perennial
Oakbrush	Lone Pine Creek/Hubbard Creek drainage (well pad and portion of access road) and unnamed tributary to Bear Creek (portion of access road)	Intermittent
Thompson Creek	Hawksnest Creek	Intermittent
Hawksnest	Hawksnest Creek	Intermittent

<u>**Drainage Characteristics and Surface Flows**</u>

Surface water resources in the study area are within the North Fork of the Gunnison River basin. The North Fork of the Gunnison River is the primary surface water feature that receives water from numerous lakes, reservoirs, and tributaries on top of the Grand Mesa and from the West Elk Mountains. Based on stream flow monitoring at Somerset, Colorado, mean annual flows in the North Fork of the Gunnison River ranged from 180 to 839 cubic feet per second (cfs) during the period 1933 through 2001 (about half of this period was influenced by Paonia Dam). Mean monthly flows ranged from 65 cfs in January to 1,927 cfs in May for this 69-year period (USGS 2002). Flow data also are available at a USGS station located near Hotchkiss, Colorado, beginning in 1997. These data show that most of the surface water flow in the drainage basin of the North Fork of the Gunnison River occurs during spring snow melt. For the rest of the year, the drainages receive flow from storms and from groundwater baseflow.

The Surface Creek drainage originates in Bonita and Cedar Mesa reservoirs located north of the Leon Lake well sites near the Delta/Mesa County line. These reservoirs provide water to upper Surface Creek via West Fork Surface and Bonita creeks. The stream flows about 20 miles in a southerly direction and empties into the North Fork of the Gunnison River. The drainage covers 39 square miles and ranges in elevation from approximately 5,200 to over 9,000 feet. Based on flow data measured at two USGS gauging stations, mean annual flow ranged from 10 to 74 cfs upstream of Cedaredge near Spaulding Peak (1941-1997 period) and 7 to 61 cfs at Cedaredge (1918 to 1997 period) (USGS 2002). Based on a hydrologic balance evaluation conducted by WWE (2003a) at these two gauging stations, Surface Creek exhibited flow reductions between the Spaulding Peak and Cedaredge USGS gauges. Stream loss was attributed mainly to irrigation diversions. Mean monthly flows at the Cedaredge gauge are shown in **Figure 3.4-1**. Flow patterns are representative of streams in the area, with peak flows in late spring or early summer and low flows in late summer through winter.

Hubbard Creek drains approximately 58 square miles, with an overall channel length of 17.6 miles. Elevation ranges from about 10,800 feet on Mount Hatten to 5,870 feet at the confluence with the North Fork of the Gunnison River. Flow and water quality sampling have been conducted at two locations in the creek as part of baseline and monitoring studies for the Bowie No. 1 and 2 coal mines. Flow ranged from approximately 3 to 87 cfs during the period September 1996 to December 1998 (BLM and USFS 2000). Based on USGS gauge data, mean monthly flows ranged from less than 1 cfs to approximately 9 cfs during spring snowmelt. Most of the year, flows in Hubbard Creek are less than 1 cfs as shown in **Figure 3.4-2.**

The Terror Creek drainage covers an area of approximately 29 square miles, with an overall channel length of 12.4 miles. The elevation ranges extend from Rex Reservoir at 11,220 feet to the confluence with the North Fork of the Gunnison River at 5,740 feet. Overall, flow measurements at four mainstream-monitoring stations ranged from less than 1 to 198 cfs (BLM and USFS 2000).

Bear Creek is an intermittent drainage that empties into the North Fork of the Gunnison River. The drainage covers approximately 8.7 square miles and ranges in elevation from 5,930 feet at the confluence with the North Fork of the Gunnison River to 9,735 feet near Buck Mesa (BLM and USFS 2000). The channel length is approximately 7.7 miles. Based on surface water monitoring at two stations, flows range from less than 1 to over 60 cfs.

Hawksnest Creek is a small intermittent stream that drains into the North Fork of the Gunnison River approximately 3 miles east of Somerset, Colorado. Flow data are lacking on this stream, but it typically is dry except for the spring and after storm events.

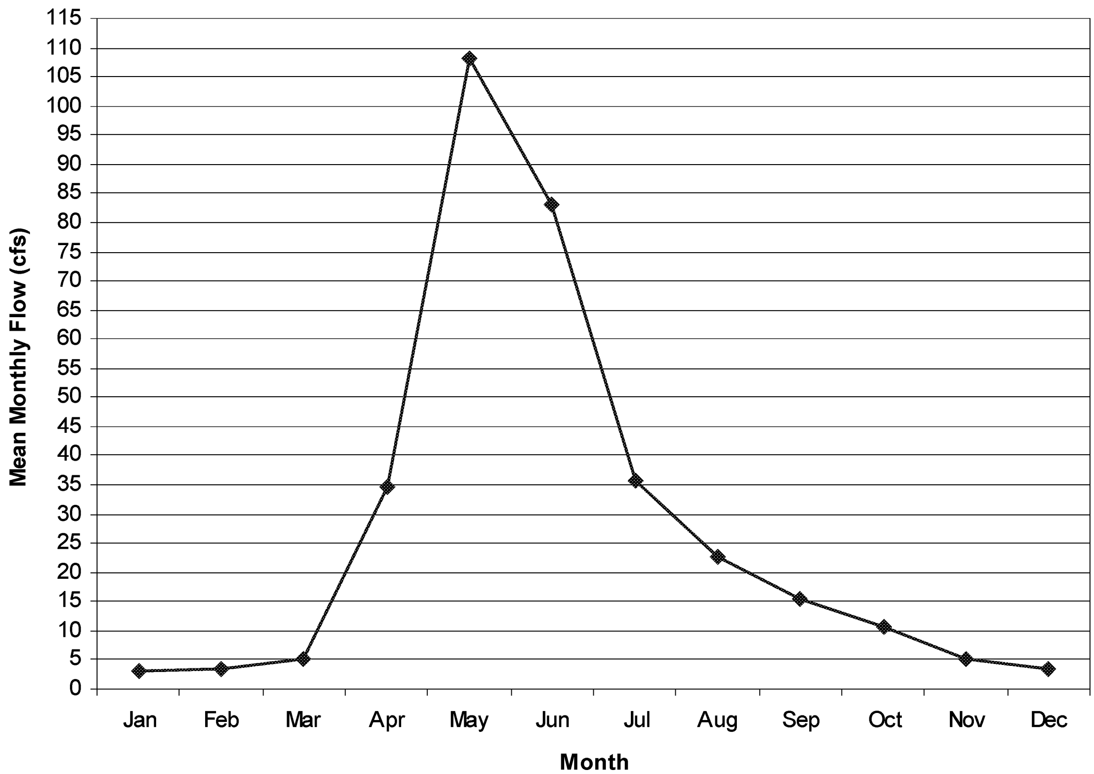

Figure 3.4-1 Annual Hydrograph for Surface Creek at Cedaredge (1917-2001)

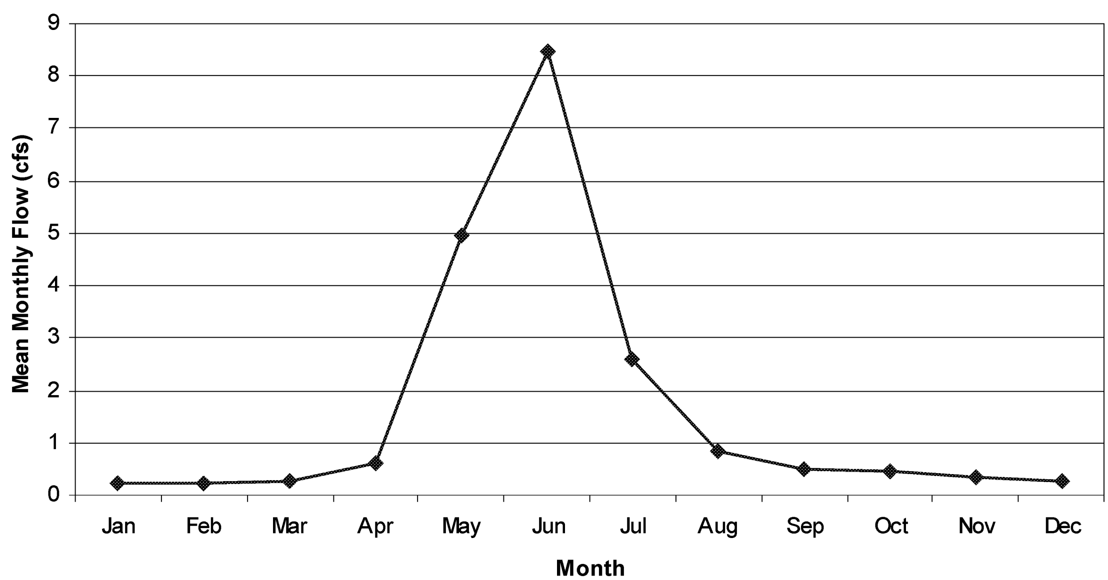

Figure 3.4-2 Annual Hydrograph for Main Hubbard Creek (1960-1968)

Floodplains

A floodplain evaluation was conducted for each of the well sites to determine their location in relation to the 100-year floodplain. Flood Insurance Rate Maps were available for two of the sites (Hawksnest and Thompson Creek). These maps indicated that the Hawksnest and Thompson Creek sites are located outside of the 100-year floodplain. For the other six sites, a 100-year flow event was analyzed for the closest stream to the well pad site using regional flood frequency equations (Vaill 2000). Cross-sectional areas were measured at representative streams in the area to determine the appropriateness of the cross-section geometry assumptions. The results indicated that all of these well sites are located outside of the 100-year floodplain.

Water Quality/Uses

Water quality information for the study area drainages was based on information from the CDPHE and Colorado Environment Water Quality Control Commission (CWQCC), CDMG, North Fork EIS (BLM and USFS 2000), Oxbow Mining monitoring (as cited in BLM and USFS 2000), WWE (2003a,b), and sampling conducted by Cordilleran Compliance Services (Appendix G).

The CWQCC uses a classification system to identify water quality standards and beneficial uses of Colorado surface waters. Beneficial use categories for the study area streams include the following:

- Recreation Class 1 – This classification is intended to protect “primary contact” with surface water where ingestion of small amounts of water is likely to occur.

- Agriculture – This classification is intended to protect waters that are used for irrigation crops and livestock drinking purposes.

- Aquatic Life Class 1 (Cold) – This classification is intended to protect waters that 1) are currently capable of sustaining a wide variety of cold water biota, including sensitive species such as trout, or 2) could sustain such biota if water quality conditions were corrected. These waters are considered capable of sustaining such biota where physical habitat, water flows or levels, and water quality conditions result in no substantial impairment of the abundance and diversity of species.

- Aquatic Life Class 2 (Cold or Warm) – This classification is intended to protect waters that are not capable of sustaining a wide variety of biota due to physical habitat, water flows or levels, or uncorrectable water quality conditions that result in substantial impairment and diversity of species.

- Water Supply – This classification is intended to protect waters suitable or intended to become suitable for potable water supplies. After receiving standard drinking water treatment, these waters would meet Colorado drinking water regulations.

The North Fork of the Gunnison River is considered an Aquatic Life Class 1, Recreation Class 1, Agriculture, and Water Supply. Surface water quality in the vicinity of Paonia is considered good with relatively low concentrations of TDS, nitrate, nitrite, and metals (BLM and USFS 2000). The water is characterized as a calcium bicarbonate type.

Water quality classifications for Surface Creek contain two categories for aquatic life. The mainstem section of the stream that is located on USFS lands is considered an Aquatic Life Class 1. In contrast, the section of the stream that is not on USFS lands is an Aquatic Life Class 2. It should be pointed out that trout have been collected in areas not located on USFS lands (see Section 3.6). Based on USGS water quality data collected near Cedaredge, mean concentrations are available for the following parameters. The period of record for specific conductance was 1976 to 2001. Samples for the other parameters were collected in 1985 and 1986.

- Dissolved ions – boron (10.0 micrograms per liter [µg/l]), calcium (11.4 mg/l), chloride (0.6 mg/l), fluoride (0.1 mg/l), magnesium (3.1 mg/l), potassium (1.3 mg/l), silica (15.3 mg/l), sodium (2.5 mg/l), sulfate (5.4 mg/l), and iron (115.0 µg/l);

- Hardness – 55 mg/l as calcium carbonate;

- pH – 7.5; and

- Specific conductance – 110.3 microhms per centimeter.

Other tributaries and the mainstem section of Surface Creek were sampled by Cordilleran Compliance Services in October 2002 within 1 mile of the Leon Lake #4 and #5 sites and near Cedaredge. The results, which are provided in Appendix G, **Tables G-1** and **G-3**, indicated that concentrations of all constituents were within Colorado drinking water standards except for iron. TDS ranges from 50 to 351 mg/l. Bicarbonate ranges from 40 to 90 mg/l, and sulfate is below 50 mg/l and often below 10 mg/l. The pH of the waters ranges from 6.0 to 8.6. Iron and manganese are the only constituents that exceed drinking water standards; iron ranges up to 0.93 mg/l with manganese usually slightly above drinking water standards. Iron and manganese are aesthetic standards in that elevated iron and manganese do not pose a health hazard but can affect the taste of the water and the hardness of the water, as well as fouling pipes. Sampling locations listed in Appendix G are shown on **Figures G-1** through **G-3**. The samples are referenced by the sample numbers (e.g., SP-CK5). The figures in Appendix G have both surface and groundwater sample locations, so the number of sample locations shown may be greater than those found in the tables in Appendix G.

CWQCC's review of Colorado stream segments in their 305(b) report concluded that Surface Creek attains stream standards for their designated uses. Surface Creek flows are maintained throughout the year to supply water for agricultural use along the lower portion of the drainage.

Surface water quality in Hubbard and Terror creeks is considered calcium bicarbonate type. Results of water quality sampling in stream segments or ponds located within 1 mile of the Powerline, Bull Park, Oakbrush, and Hubbard Creek sites are provided in Appendix G, **Tables G-4** through **G-7**. The TDS ranges up to 402 mg/l, and the pH ranges from 7.0 to 9.3. Bicarbonate ranges from about 50 mg/l to an upper range of 70 to 80 mg/l. Sulfate is usually below 10 mg/l. Iron ranges up to 14.0 mg/l, and manganese ranges up to 0.23 mg/l. These surface waters are suitable for domestic use, except for the high iron, which may create problems with fouling of pipes and taste. Both streams are considered Aquatic Life Class 1, Recreation Class 1, Agriculture, and Water Supply. Based on CWQCC's review of these streams (303[d] list), designated uses were fully supported or attained for all water standards except Aquatic Life Class 1. This use was not attained due to elevated levels of selenium and other metals, especially when the drainage crosses or lies downstream of Mancos Shale outcrops. CWQCC identified agricultural activities as the source of the elevated metal concentrations. These streams are targeted for the Total Maximum Daily Load process for 2004 (CWQCC 2002). This process allocates loads of the contaminant of concern among various sources discharging to the stream, naturally occurring background sources, and a safety margin to help meet stream water quality standards and designated uses.

Previous monitoring of TDS and total suspended solids (TSS) in Bear Creek has revealed relatively high values. In 1980 to 1982, lower Bear Creek showed average concentrations of 2,300 mg/l (TDS) and 75 mg/l (TSS). Concentrations in upper Bear Creek were considerably lower than the lower portion of the creek (247 mg/l for TDS and 31 mg/l for TSS).

Results of water sampling within 1 mile of the Hawksnest and Thompson Creek sites are included in Appendix G, **Tables G-8** and **G-9**.

<u>**Surface Water Rights and Beneficial Uses**</u>

For purposes of summarizing surface water rights and beneficial water uses for the well sites, the Colorado Decision Support System database was queried for water rights data (www.cdss.state.co.us). This data search was combined with a review of well permit records from the Colorado State Engineer's Office (SEO) in Denver, which is discussed separately in Section 3.4.1.2. The SEO database is important because it can identify small capacity water wells that may not have adjudicated water rights. The study area is located within the Colorado Division of Water Resources Division 4, District 40. When examining a 1-mile radius from the proposed well sites, four surface water rights were identified: Carol Spring and Cole Reservoirs #4 and #5 for the Leon Lake #4 and #5 sites; and Garvin Mesa Pipeline Company for the Bull Park site (Appendix H, **Table H-1**). Uses for these water rights are domestic, livestock, and irrigation.

Data searches also were conducted for downstream water rights associated with the closest perennial stream to the well sites. More specifically, Leon Lake #4 and #5 are located in the Surface Creek drainage, Bull Park and Powerline are located in the Terror Creek drainage, and Hubbard Creek is located in the Hubbard Creek drainage. The Oakbrush site and access road are located in the Hubbard Creek drainage, while a portion of the new access road is in the Bear Creek drainage. There is one decreed water right for irrigation in the Bear Creek drainage. Hawksnest and Thompson creeks are located in the Hawksnest Creek drainage, which has no decreed water rights. The following information summarizes water rights and beneficial uses in the downstream drainages between the proposed well sites and the North Fork of the Gunnison River. The water right locations and flow rates are listed in Appendix H, **Table H-2**.

- Approximately 670 cfs of absolute flow rights are decreed for Surface, Terror, and Hubbard creeks in the vicinity of and downstream of the proposed well sites, as shown in Appendix G, **Figures G-1** through **G-3**. Decreed water rights by drainage are about 510 cfs for Surface Creek, 90 cfs for Terror Creek, and 70 cfs for Hubbard Creek. Absolute volume decrees for reservoirs in these watersheds total about 4,380 acre-feet for Surface Creek, 990 acre-feet for Terror Creek, and 650 acre-feet for Hubbard Creek.

- Many domestic use decrees are combined with irrigation or municipal uses. The net absolute decreed flows associated with domestic surface water use are approximately 40 cfs or less for Surface Creek, 3 cfs or less for Hubbard Creek, and 6 cfs or less for Terror Creek. Most of this water is associated with diversions from ditches. Additional domestic water uses are decreed for reservoir storage including the Blue Ribbon Reservoir #1 (10 acre-feet for industrial/domestic uses) in Hubbard Creek; Doughty Reservoir #2 (30 acre-feet for irrigation/municipal/domestic uses) in Surface Creek; and Pitkin Lake (10 acre-feet for domestic use) and Pupik Pond (2 acre-feet for domestic use) in Terror Creek.

- Small decreed municipal water uses are present in the Surface Creek and Terror Creek drainages downstream of the proposed well sites. The net absolute decreed flow rates associated with municipal surface water use are less than 2 cfs for Surface Creek and less than 3 cfs for Terror Creek. Most of the municipal use is combined with domestic or irrigation use. No municipal use occurs in the Hubbard Creek drainage.

- In terms of decreed flow rates exceeding 1 cfs, the following domestic and municipal users occur in the three drainages downstream of the proposed well sites: Cedar Mesa Ditch (24 cfs and 2 cfs), Cedaredge Pipeline (1 cfs), Lone Pine Ditch (2 cfs), Orchard City Pipeline (1 cfs), and Sooner Ditch (1.5 cfs) in Surface Creek; Fawcett Ditch (1.2 cfs), Pitkin Mesa Pipeline (2 cfs), and Terror Ditch (1.5 cfs) in Terror Creek; and Blue Ribbon Ditch #1 (2 cfs) and Deertail Ditch (1 cfs) in Hubbard Creek.

- The Upper Surface Creek Domestic Water Users Association has proposed a new municipal water diversion that would be located approximately 4 miles downstream of the Leon Lake #4 and #5 sites (T12S, R94W, Section 34). The projected startup date is the fourth quarter of 2004. Presently the Association uses the Town of Cedaredge's water supply.

- Numerous water rights held by the USFS and BLM also exist within a 5-mile radius (adjacent or downstream) of the well sites. The BLM holds three decreed in-stream water rights: 0.011 cfs in Bear Creek, 0.012 cfs in Terror Creek, and 0.011 cfs in Hubbard Creek. The locations of these water rights are listed in Appendix H, **Table H-1**. USFS water rights located within a 5-mile radius of the well sites consist of storage rights for stock ponds, as listed in Appendix H, **Table H-3**.

3.4.1.2 Groundwater

The study area for groundwater extends from the Cedaredge and Hotchkiss areas on the west to Paonia Reservoir on the east. The southern boundary would be at the approximate latitude of Paonia, Colorado, and the northern boundary would be approximately at the northern extent of T12S. This study area also comprises the cumulative effects area.

Groundwater resources along the North Fork of the Gunnison River and in the study area are found in thick alluvial deposits along the North Fork of the Gunnison River, in glacial and colluvial deposits found in the valleys in the study area, and in the Cretaceous and Tertiary bedrock lithologic units. This section presents a summary of groundwater resources in the study area. A more detailed discussion of both surface and groundwater resources can be found in *Characterization and Assessment of Water Resources on the Southeastern Flank of Grand Mesa, Delta, Gunnison, and Mesa counties, Colorado* (WWE 2003a). Reports on groundwater in the Grand Mesa area by Brooks and Ackerman (1985) and Brooks (1983) of the USGS provide the current understanding of groundwater movement in the study area. These reports are considered adequate for characterization of groundwater in the project area.

Hydrostratigraphic Units

The geology and stratigraphy of the study area are described in Section 3.3.1. Cross sections of the stratigraphy are shown in Appendix J. This section summarizes the water-bearing properties and aquifer characteristics of the bedrock stratigraphic units and the overlying glacial and colluvial sedimentary deposits.

Mancos Shale. This is the lowest (i.e., oldest) bedrock stratigraphic unit that would be affected by the Proposed Action (**Figure 3.3-1**). The Mancos Shale acts as a hydrologic seal for the overlying Mesaverde Formation and prevents the downward migration of groundwater. The upper 10 to 20 feet of the Mancos is commonly fractured and weathered, especially where the Mancos is found in outcrop or exposed over large areas of the North Fork of the Gunnison River basin. The Mancos can contain water and locally the Mancos provides limited water to domestic wells. The Mancos does not supply municipal water because the unit is mostly a tight clay and does not yield appreciable water to wells. Private domestic wells in the Mancos have yields of 5 to 15 gallons per minute (gpm), and springs can have yields up to 25 gpm but usually have flow rates of 10 gpm or less (Brooks and Ackerman 1985). There are no aquifer test data available for the Mancos. There are records of 10 domestic wells of record in the Mancos Shale.

Mesaverde Formation. This formation consists of five members. The aquifer characteristics of the members are described below.

- Cozzette Member: This unit is found in the Cedaredge area and interfingers with the underlying Mancos Shale. No hydrologic studies or aquifer tests have been conducted on this unit. The unit is not known to be water-bearing and is not a water supply aquifer in the study area.

- Rollins Sandstone Member: The Rollins Sandstone can be locally water-bearing. The sands often contain a calcareous cement that lowers the porosity and permeability of the unit. The upper part of the Rollins is a porous sand 5 to 20 feet thick that yields water to wells and locally supplies water to springs and seeps. This is the main water-bearing part of the Rollins Sandstone. There are no aquifer test data available on the Rollins, but in the Cedaredge area this unit is a source of private domestic water supply (WWE 2003a). The Rollins is recharged where it is exposed at the surface by water flowing in creeks during spring runoff and by overlying saturated glacial and colluvial units. The recharge occurs along secondary features such as faults and fractures. In the eastern part of the project area, Terror Creek recharges the Rollins Sandstone and loses about 0.59 cfs to the Rollins and the Cameo members of the Mesaverde Formation (CDMG 2001) through the extensive network of faults and fractures found along the lower part of the creek. Yields to wells screened in the Mesaverde Formation range from 0.7 to 24 gpm, with the higher values coming from the Rollins Member. Springs can have flows up to 25 gpm in the Mesaverde, with most springs having flows generally less than 10 gpm. The higher spring flows are often found in the Rollins Member because of the permeability of the upper sand unit and because of the recharge of the Rollins by water flowing along the lower reaches of creeks in the project area. Although the Rollins Sandstone can be locally water-bearing, especially in the upper 20 feet where the porous sand member is present, the unit is not a regional aquifer in the study area.

- Cameo or Coal-Bearing Member: The coal-bearing member of the Mesaverde Formation is the most studied unit in the Mesaverde because of the past need for dewatering in some of the coal mines that dominate the outcrop of the Mesaverde along the North Fork of the Gunnison River. The unit is about 300 feet thick on the west side of the project area and 650 to 700 feet thick on the east side. The coal seams range from 10 to 150 feet in thickness and have low primary permeability. However, fractures in the coal seams and burned zones at the outcrop within the coal provide increased secondary permeability that allows for surface water from creeks and groundwater from overlying saturated glacial and colluvial units to enter the coal mines. Thus, some of the coal mines have found it necessary to dewater, especially after spring runoff. Aquifer tests in the Cameo Member showed transmissivity estimates ranging from 1.5 to 16.7 square feet per day (ft^2/day), with storage coefficient estimates ranging from 0.097 to 4.4×10^{-5} (Brooks and Ackerman 1985). The more permeable burned zones can extend for 500 to 1,500 feet into the Cameo Member from the outcrop and are due to burning of the coal at some time during the geologic past. These burned zones usually carry water because of the increased secondary permeability of the coal seam. Coal mines above creek elevations and above the elevation of glacial and colluvial units in the valleys are usually dry and have water inflow rates of 10 gpm or less. Coal mines below creeks such as Terror Creek or below thick glacial and colluvial outcrops, such as are found in the Cedaredge area, can have water inflow along fractures, especially during spring runoff. Mine inflow rates of 1,500 gpm have been reported by the Bowie No. 1 Mine (CDMG 2001). These inflows are probably due to faults or fractures (Bowie Resources Ltd. 1996). The Cameo Member of the Mesaverde is not an aquifer because of its low primary permeability, but this unit can contain considerable water where it lies below creeks and water-saturated glacial and colluvial material along the North Fork of the Gunnison River. Also, sandstone units interbedded with the coal seams can be permeable and locally contain groundwater.

- Barren Member: The primary permeability of the Barren Member is very low due to cementation of the sandstones and siltstones and the predominance of clay in most of the lithologic units. The Barren Member is not water-bearing and does not constitute an aquifer because of its very low transmissivity. Limited aquifer tests in the more permeable parts of the Barren Member have given estimates of transmissivity of 0.33 ft^2/day (WWE 2003a). This is a very low transmissivity and suggests that water in the Barren Member occurs only in localized lenses of the unit that have more permeable sands. Some of these more permeable local sand lenses have yielded limited groundwater to domestic wells. However, groundwater is not transmitted through the unit along a hydraulic gradient because the Barren Member has insufficient groundwater to develop a potentiometric surface or groundwater table. The Barren Member also is a tight sand relative to the movement of natural gas.

- Ohio Creek Member: The upper part of the Ohio Creek is water-bearing and provides flow to springs and seeps.

Wasatch Formation. The Wasatch in the project area contains a conglomerate at the lease and lenticular sandstone units in the lower part of the stratigraphic section, especially in the McClure Pass area. For the most part, the Wasatch has low horizontal and vertical permeability because of its high clay content and is not water-bearing. The Wasatch is not a aquifer in the project area. However, this unit can be locally water-bearing and can yield water to domestic wells and provide flow to springs and seeps because of the various rock types and the local presence of conglomerates and porous sand units in the stratigraphy (WWE 2003a).

Green River Formation. The permeability is low to moderate, and the common presence of wetlands in areas where the Green River is exposed on the Grand Mesa suggests that the permeability to water is generally low. No aquifer studies have been conducted on this unit in the project area. Because of the low permeability of the Green River Formation, this unit is not an aquifer in the study area.

Uinta Formation. The presence of wetlands, lakes, and reservoirs in this unit throughout the Grand Mesa attests to the low permeability of this clay-rich unit. No aquifer studies have been conducted on this unit in the study area. Because of the low permeability of the unit and the general lack of wells in the Uinta, this unit is not considered to be an aquifer in the study area.

Pleistocene and Younger Glacial, Alluvial, and Colluvial Deposits. These deposits are generally unconsolidated and consist of glacial deposits formed by alpine glaciers during the Pleistocene and younger surficial deposits formed by landslides, debris flows, mudflows, and streams. The debris flows are the most extensive of the unconsolidated deposits (WWE 2003a) and formed during past geologic periods of high precipitation. These debris flows consist of a heterogeneous mixture of clay, silt, sand, gravel, and boulders derived from the surrounding bedrock lithologic units. Debris flow deposits and glacial deposits are most common in the broad valley found in the Cedaredge and Hotchkiss area. Unconsolidated deposits of sand, silt, clay, and gravel also are common on the mesas in the study area. These deposits are remnants of much larger deposits that have been eroded away by incision of the Grand Mesa. Unconsolidated deposits are commonly 50 to 100 feet in thickness and often reach 200 to 250 feet in thickness in the valleys. These unconsolidated sedimentary deposits are water-bearing and are the main source of water for private domestic wells in the Grand Mesa area and especially in the study area.

The unconsolidated deposits found on mesas and in the valleys of the study area, especially in the western portion, are very permeable because of their unconsolidated and coarse-grained nature. These deposits form local aquifers that provide groundwater to wells and feed most of the known springs and seeps. Where these deposits overlie faults and fractures in the Mesaverde Formation, such as in the Cedaredge area, the unconsolidated deposits can act as a recharge source for the upper Mesaverde units because of the hydraulic head created by the saturated nature of these unconsolidated deposits. The permeability of the unconsolidated sedimentary deposits is often 100 times that of the sandstone coal-bearing units of the Mesaverde Formation (WWE 2003a). Transmissivity estimates for these units reported by Brooks (1983) ranged from 108 to 230 ft^2/day for the alluvium of Stevens Gulch to 1900 ft^2/day for Quaternary unconsolidated deposits. Storage coefficient estimates ranged from 0.002 to 0.2 gpm. Wells in the unconsolidated deposits have recorded yields of up to 200 gpm.

Groundwater Flow and Quantity

There are no regional aquifers in the study area. Most groundwater used for municipal and domestic consumption comes from alluvium along the North Fork of the Gunnison River or from the unconsolidated Pleistocene and younger glacial, colluvial, and alluvial sedimentary units found along the tops of mesas and especially along the sides and bottoms of major valleys. Bedrock lithologic units contain groundwater only locally, and this groundwater is usually limited to highly permeable sand units or areas of secondary permeability created by faults and fractures. None of the bedrock lithologic units are transmissive to groundwater, thus limiting groundwater flow to very local areas of high permeability. The unconsolidated deposits generally contain ample groundwater for domestic use, but are isolated from one another and thus do not constitute a regional aquifer.

Mesaverde Formation

The Rollins Sandstone is sometimes referred to as a regional aquifer because it contains groundwater in both the Cedaredge area and in the Terror Creek and Hubbard Creek drainages along the North Fork of the Gunnison River. The Rollins Sandstone is the most permeable member of the lower part of the Mesaverde Formation, and it frequently yields water to wells in the Cedaredge area because it is recharged at the outcrop by groundwater from the overlying saturated unconsolidated glacial and colluvial sediments. In the Terror and Hubbard Creek areas, this unit also contains groundwater because it is recharged by infiltration from Terror Creek and from the North Fork of the Gunnison River. The Rollins also has an artesian head of 170 feet in monitor well MW-34B of the Bowie No. 2 Mine (Bowie Resources Ltd. 1996).

The Rollins is not a regional aquifer, but it is a local source of groundwater where it receives ample recharge from overlying unconsolidated sediments or streams. The artesian head in the Bowie No. 2 Mine area is due to connate (i.e., water trapped during deposition on sedimentary rock) marine water trapped when the Rollins Sandstone was laid down and consolidated into a sandstone during the late Cretaceous. This connate marine water is very saline and high in chloride and thus is not suitable for domestic use. Groundwater in the Rollins that is suitable for domestic use is found mainly in the North Fork of the Gunnison River in areas where the Rollins is exposed in outcrop (WWE 2003a).

Based on reports by Brooks and Ackerman (1985) and the data and analysis presented by WWE (2003a), the Cameo or Coal-bearing Member of the Mesaverde does not appear to be a good aquifer. In addition to coal layers, the Cameo Member contains sandstone lenses interbedded with the coal. However, these sandstone lenses seldom yield water to wells, and the groundwater in them is considered to be perched because of the limited areal and vertical extent of the sandstones. Available groundwater is present in the coal seams when they are in close proximity to unconsolidated deposits or the outcrop. Groundwater in the coal seams is the result of infiltration of stream water, especially in the Terror Creek and Hubbard Creek drainages, or the result of downward migration of groundwater from overlying saturated unconsolidated colluvial and glacial deposits, as is the case in the Cedaredge area. The primary mechanism for water entering the coal seams is through secondary permeability generated by fractures, faults, and fracturing of the coal in the burned areas that extend from 500 to 1,500 feet in from the exposures of the coal. In the Bowie No. 2 Mine, the “D” and “E” coal seams have perched groundwater that can feed local springs and seeps (Bowie Resources Ltd. 1996).

Groundwater Flow to Wells

Approximately 71 percent of the domestic wells of record in the study area are screened in the unconsolidated Pleistocene and younger glacial, colluvial, and alluvial sediments (WWE 2003a). These private wells can have yields up to 85 gpm. Fourteen percent of the wells of record are screened in bedrock units and have flow rates up to 24 gpm. Most of these bedrock wells have flow rates of 10 to 15 gpm or less. The percentage of wells in the other formations include 2 percent in the Wasatch, 1 percent in the Uinta, and 8 percent in the Mesaverde. Flow rates for these wells usually range from 1 to 8 gpm. According to the inventory reported by WWE (2003a), approximately 15 percent of the wells in the study area are screened across both bedrock and unconsolidated alluvial units. These wells have yields up to 30 gpm. Ten wells of record obtain water from the Mancos Shale with yields of up to 24 gpm. Twenty wells are found on the Grand Mesa screened in basalt flows with yields of 6 to 24 gpm.

The inventory of WWE (2003a) found 36 wells screened in the Mesaverde Formation, most of them in the Cedaredge area. These wells had yields of 2 to 24 gpm, with most wells having yields in the 10 to 15 gpm range. These wells are located in areas where the Mesaverde is more permeable due to higher permeability in the sand units, increased density of faults and fractures, burned coal zones, weathering of the Mesaverde, or recharge to the Mesaverde Formation from overlying unconsolidated alluvial sediments saturated with groundwater.

Groundwater Flow to Springs

Groundwater flow to springs is primarily from river alluvium along the North Fork of the Gunnison River and from the unconsolidated Pleistocene and younger glacial, colluvial, and alluvial sediments. Most shallow groundwater in the study area is contained within these unconsolidated materials. River alluvium produces springs because of the recharge to the alluvium from high flows and high river stages during spring runoff. Springs in the unconsolidated glacial, colluvial, and alluvial sediments are often found at the base of these units where the unconsolidated sediments rest on bedrock. Flow rates to springs generally range from approximately 2 to 10 gpm, but they can be as high as 20 to 25 gpm. These springs are a major source of water for wildlife and a local source of municipal water. Crop irrigation on broad alluvial mesas and areas of extensive alluvial material, such as in the Cedaredge area, results in increased flow from the springs. Bedrock springs are found where unconsolidated alluvial sediments overlie the bedrock, or the bedrock is fractured. These bedrock springs are recharged by downward flow from the overlying alluvial sediments from spring snowmelt and rains, stream infiltration, and local irrigation practices. Some bedrock springs in the Mesaverde Formation, especially in the eastern part of the study area, are fed by seepage from coal-bearing horizons.

Municipal Water Supply

Municipal water supply in the study area is primarily obtained from surface water or reservoirs fed by surface water flow. Paonia obtains its water from colluvial springs on Mount Lamborn, south of the North Fork of the Gunnison River. Cedaredge obtains water from springs that flow from the unconsolidated colluvial and alluvial sediments, surface water, and from Surface Creek Reservoir. Hotchkiss uses Leroux

Creek for water. Orchard City obtains water from springs, Surface Creek, and reservoirs on Grand Mesa. The town of Lazear uses groundwater wells, while the Somerset Water District has wells in the river alluvium of the North Fork of the Gunnison River. The Mesaverde Formation and other bedrock lithologic units are thus not a source of municipal water in the study area. They supply very limited water to private domestic wells.

Groundwater Quality

Groundwater quality in the Grand Mesa area and especially in the study area along the North Fork of the Gunnison River is controlled by the mineralogy of the rocks through which the water flows, the residence time of the water in the rocks, and the flow path taken by the groundwater. Studies by WWE (2003a) and Brooks and Ackerman (1985) have shown that there are four basic types of groundwater in the study area:

- Calcium bicarbonate groundwater found mainly in river alluvium and unconsolidated alluvial, colluvial, and glacial sediments, as well as in streams.
- Sodium bicarbonate groundwater found mainly in bedrock lithologic units such as the non-marine members of the Mesaverde Formation.
- Sodium chloride groundwater found mainly as connate water in bedrock lithologic units of marine origin, such as the Rollins Sandstone (WWE 2003a; Brooks and Ackerman 1985).
- Sodium, calcium, and magnesium sulfate groundwater found mainly in seeps, springs, and mine discharge related directly to coal seams.

Groundwater found in wells, springs, and seeps can be related back to its origin through its water chemistry. Calcium bicarbonate water is shallow groundwater found in unconsolidated sediments that have been recharged directly by streams or precipitation. This water had a relatively short residence time in the lithologic units from which it is withdrawn or from which it is naturally discharging. All municipal supply groundwater and most domestic wells utilize the shallow groundwater dominated by calcium bicarbonate because the salinity or TDS is generally below 500 mg/l and the water quality meets Colorado drinking water standards. Some domestic wells screened in the upper Mesaverde Formation utilize groundwater that is a mixture of shallow alluvial groundwater dominated by calcium bicarbonate and groundwater found in the more permeable sand lenses of the Mesaverde, which is usually dominated by sodium bicarbonate. This mixed groundwater can have a TDS between 500 and 1000 mg/l and still be suitable for domestic consumption. Mine discharge water, connate marine water in the Rollins Sandstone, and most groundwater in the Mesaverde Formation are not suitable for domestic consumption because of the high salinity. Groundwater analyses provided by WWE (2003a) are presented in Appendix I. Sample locations for samples listed in Appendix G are shown on **Figures G-1** through **G-3**. The samples are referenced by the sample numbers (e.g., SP-CK5). The figures in Appendix G have both surface and groundwater sample locations, so the number of sample locations shown may be greater than those found in the tables in Appendix G.

Alluvial groundwater in the study area is found mainly in river alluvium along the North Fork of the Gunnison River. This water generally has a pH between 7.5 and 8.5, bicarbonate in the range of 150 to 500 mg/l, bicarbonate greatly in excess of sulfate, chloride values below 20 mg/l, nitrate within the Colorado drinking water standard of 10 mg/l, and a salinity or TDS ranging from 200 to 700 mg/l. This water is calcium bicarbonate dominated and suitable for human consumption.

Cedaredge Area

Groundwater in the Cedaredge area has been sampled through wells and springs and some mine discharges (WWE 2003a). Spring water in the Cedaredge area is dominated by calcium bicarbonate, indicating that the groundwater is directly recharged by precipitation, and has a TDS in the range of 585 to 915 mg/l. The pH ranges from 7.7 to 8.7 in samples taken by WWE (2003a). Iron can exceed the state drinking water standard of 0.3 mg/l and range up to 14.0 mg/l. All other constituents are within Colorado drinking water standards.

Well water in the Cedaredge area is very similar to spring water because most of the wells are screened in unconsolidated alluvial, colluvial, and glacial sediments. Well water sampled by WWE (2003a) showed TDS ranging from 290 to 556 mg/l, pH between 7.0 and 8.4, and sulfate less than 50 mg/l. The maximum depth of the wells sampled was 211 feet. All other constituents were within Colorado drinking water standards.

Groundwater in wells in the Leon Lake #4 and #5 well area (near Spaulding Peak) has TDS values ranging from 224 to 552 mg/l and is dominated by calcium bicarbonate. The wells are from 132 to 328 feet in depth. The pH is between 7.3 and 7.5, and sulfate is below 50 mg/l. Iron and manganese exceed the Colorado drinking water standards, with iron ranging up to 0.4 mg/l and manganese up to 0.07 mg/l. All other constituents are within drinking water standards. This water is thus derived from shallow groundwater in the colluvial sediments found in this area.

Springs in the Spaulding Peak area are similar to well water quality. The TDS ranges up to 394 mg/l but is often below 100 mg/l. The pH is between 6.4 and 7.9, and sulfate is below 50 mg/l. The water is dominated by calcium bicarbonate. Iron and manganese exceed drinking water standards, with iron ranging up to 2.7 mg/l and manganese up to 1.3 mg/l. All other constituents are within drinking water standards.

Bear Creek, Terror Creek, and Hubbard Creek Areas

Groundwater in these areas comes from springs. No wells in these areas were available for sampling. Springs have TDS values around 214 mg/l, pH values of 7.46 to 7.49, and groundwater dominated by calcium bicarbonate. Sulfate is less than 50 mg/l. All constituents are within drinking water standards.

A spring sampled near the Bull Park proposed well site had a TDS value of 374 mg/l, a pH of 8.56, and sulfate less than 50 mg/l. The water was dominated by calcium bicarbonate. Iron was the only constituent that exceeded drinking water standards.

No groundwater samples were available from the Oakbrush, Hawksnest, and Thompson Creek project areas, due to lack of available wells for sampling.